CHINA'S ENERGY
A FORECAST TO 2015

E. Iain McCreary
Alan Y. Gu
Verne W. Loose
Joseph M. Roop

U.S. DEPARTMENT OF ENERGY
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A Forecast to the Year 2015

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Project Lead, Supply Forecast, Classified Appendix

Author and Lead Researcher: E. Iain McCreary

Editor and Project Head: Verne W. Loose

and

Pacific Northwest National Laboratory

(Battelle Northwest)

Technical Support, Demand Forecast

Demand Section Author: Alan Y. Gu

PNNL Coordinator: Joseph M. Roop

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Point of Contact:

Los Alamos National Laboratory

Verne W. Loose

TSA-4 MS F604; *Energy & Environmental Analysis*

Los Alamos, NM 87545

(505) 665-5666 ph. (505) 665-5125 fax. loose@lanl.gov

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SCOPE NOTE

This project was sponsored by the U.S. Department of Energy's Office of Energy Intelligence, NN-30, as part of their energy security program. China looms as the single largest source of energy demand for the next two decades and as such, has the potential to adversely affect world energy markets and U.S. energy security through increased competition for available resources.

The work was conducted jointly by Los Alamos National Laboratory (LANL) and Pacific Northwest National Laboratory (PNNL). PNNL researched the energy consumption (demand) section and provided a computational model for the demand forecast, while Los Alamos was responsible for the sections on energy production (supply), Chinese national infrastructure, and integration of the report. Any errors discovered herein are the responsibility of Los Alamos National Laboratory.

As this report is an attempt to peer two decades into the future, it is perforce, speculative. Projections are based on recent historical trends which may be disrupted by dramatic changes in energy prices or catastrophic failure of any domestic Chinese energy industry, or a host of other unforeseen events. To hedge against this uncertainty, two scenarios are offered for both production and consumption. Each projection offers an expected, or "business as usual" scenario and a more optimistic "maximum" or "energy efficient" scenario.

Determination of the impact of Chinese petroleum imports on U.S. energy security was made by comparison of our import projections with other projections by the International Energy Agency (IEA), World Bank and several other international energy analysis groups. The unwavering consensus of all these agencies was that Chinese imports would not significantly affect world energy markets. The independent world energy price model which was to be supplied by PNNL to corroborate this conclusion was unavailable at the time this publication went to press.

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UNITS

bl	barrel
Bbl	billion barrels
toe	tons oil equivalency
Mtoe	million (x 10^6) tons oil equivalency
Btoe	billion (x 10^9) tons oil equivalency
tce	tons coal equivalency
Mtce	million (x 10^6) tons coal equivalency
Btce	billion (x 10^9) tons coal equivalency
W	watt
kW	kilowatt (x 10^3 watt)
MW	megawatt (x 10^6 watt)
GW	gigawatt (x10^9 watt)
Wh	watt hour
TWh	terrawatt (x10^{12} watt) hour
J	joule
GJ	gigajoule (x10^9 joule)
cal	calorie (heat)
m	meter
km	kilometer
p.a.	per annum (per year)

CONVERSIONS

Standard Coal:	1 ton	= 29.310 GJ	= 1.000 tce	= 5.14 bl oil	= 7.00 kcal
Chinese Average Coal	1 ton	= 20.943 GJ	= 0.714 tce	= 3.68 bl oil	= 5.00 kcal
Chinese Average Crude	1 ton	= 41.868 GJ	= 1.429 tce	= 7.35 bl oil	= 10.00 kcal
Chinese Average Crude	1 bl	= 5.694 GJ	= 0.199 tce	= 1.00 bl oil	= 1.36 kcal
Standard Natural Gas	10^3 m^3	= 37.68 GJ	= 1.29 tce	= 6.62 bl oil	= 9.00 kcal
Chinese Avg. Nat. Gas	10^3 m^3	= 38.98 GJ	= 1.33 tce	= 6.85 bl oil	= 9.31 kcal

Chinese Electrical Capacity Equivalency :	1 GW = 4.5 TWh
Coal to Oil Conversion:	1.0 tce = 0.7 toe
Oil to Coal Conversion:	1 toe = 1.429 tce
Oil to Oil Conversions:	1.0 toe = 7.19 bl oil *(IEA standard oil conversion rate)*

CHINA’S ENERGY

DESCRIPTION OF TERMS

In the following discussion of Chinese energy, the terms “consumption” and “production” are used rather than “supply” and “demand”. Although similar, consumption and production are measures of physical quantities, and lack the economic data needed to calculate true “demand” or “supply”.

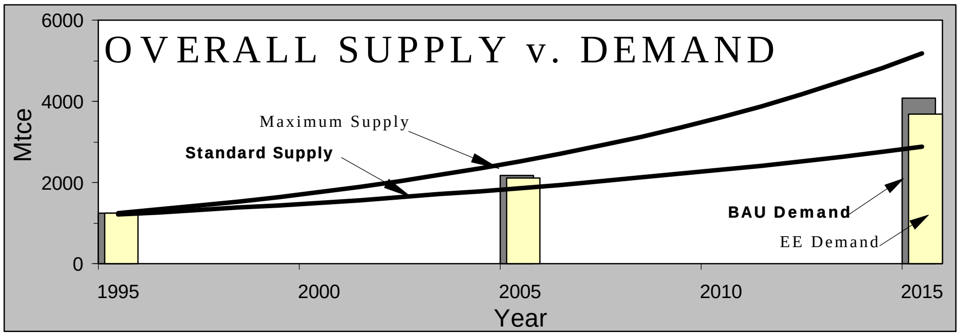
Consumption refers to the actual energy used, or forecast to be used by the Chinese, measured in tons of energy resource. It is an incomplete reflection of energy demand, in that it perforce does not contain information about the price of the resource. In the Energy Consumption chapter (Section III) consumption is forecast in Mtoe, or million tons of oil equivalent. This is a measure of how much energy the Chinese would consume if all energy resources (coal, electricity, natural gas, etc.,) were assumed to be oil. The oil equivalency measure was chosen to allow easy comparison with other sources, including the International Energy Agency (IEA) and the World Bank, which both use oil equivalency as a standard unit.

Production is a measure of the total energy available, from all resources including coal, oil, natural gas, and electricity generation. It is an incomplete measure of supply, which like demand, is related to cost data. Because coal is the dominant Chinese energy resource (contributes 73% to consumption), and because most of the reference texts use coal as a measure of Chinese energy production, data is given in Mtce, or million tons of coal equivalent. This coal equivalency unit is used in both the Summary and Energy Production chapters (Sections I & II).

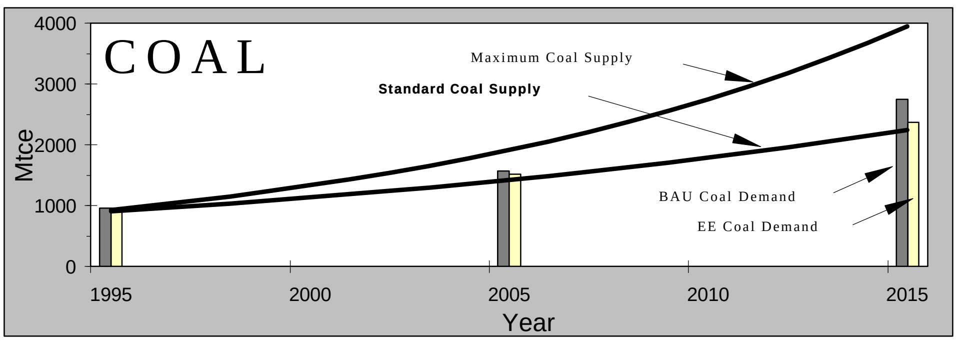
Conversion from oil to coal equivalents a simple matter of dividing the oil equivalency by 0.7 (see UNITS & CONVERSIONS, opposite).

CHINA 'S ENERGY

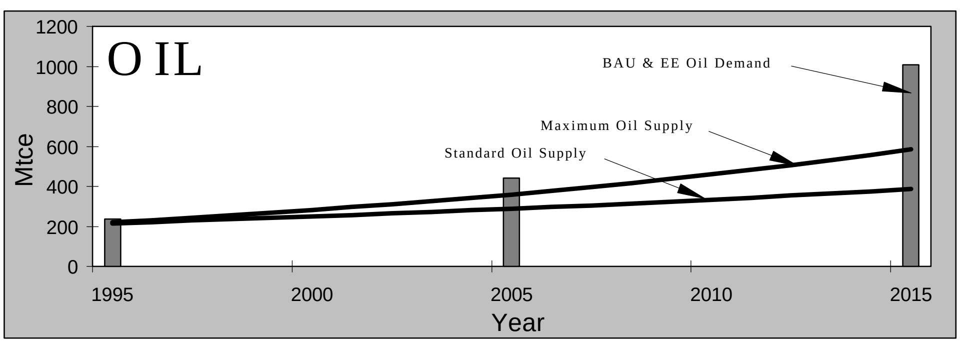
All plots have both domestic supply and demand data displayed. Supply data is represented by two curves, displaying the Maximum Scenario (best case) and Standard Scenario (expected) data. Demand data is displayed as bars for the years 1995, 2005 and 2015. The bars represent the Business As Usual (BAU) and Energy Efficient (EE) demand scenarios. For both supply and demand, actual energy production or consumption will fall between the two values.



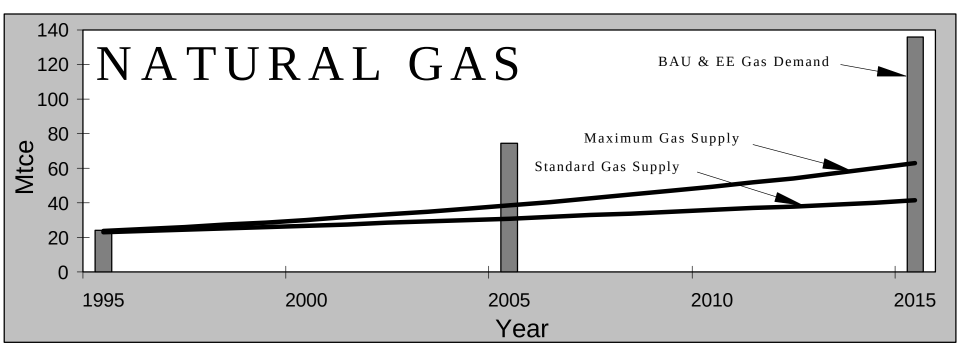
China can produce enough total energy resources for overall supply to meet demand, but fuel substitution and an increased dependence on coal will be required.



Coal can be extracted in excess of current demand trends, and will be used as a substitute for other fuels.



China faces major oil shortages of 5.9 to 8.8 million barrels per day by 2015



As residential demand drives demand for this resource, imports will continue.

CHINA'S ENERGY

KEY FINDINGS

GENERAL:
- Easy to consider China as "energy poor" despite a wealth of raw materials:
    - ⇨ Per capita energy consumption is one-sixth that of OECD countries.
    - ⇨ Energy consumption per dollar of GDP is ten times higher than OECD countries.
- Energy demand growing faster than supply.
- Major disconnects between available and required fuel types.
    - ⇨ Domestic energy supply is almost entirely coal, while urban consumers want clean household fuels like electricity and natural gas.
    - ⇨ Growth in industry and transportation have increased demand for oil and petroleum products, forcing China to become a net importer.
- Consumption centers far from resources.
    - ⇨ Transportation infrastructure critical to energy development.
    - ⇨ Rail freight capacity overloaded.

CONSUMPTION:
- Energy demand is expected to increase exponentially.
- Industry will continue to dominate consumption at 60% of total.
- Transportation fuels consumption will quadruple by 2015.
- Consumption in commercial buildings will increase seven fold by the year 2015.
- Demand for oil will force imports of up to 8.6 million barrels per day by 2015.

PRODUCTION:
- Coal will remain the dominant energy source.
- Oil and natural gas imports will increase dramatically. Oil imports will reach a maximum of 8.8 million barrels per day in 2015.
- China's proposed development of electrical power industry is financially achievable.
- Chinese domestic manufacturing capacity is insufficient to maintain growth. Between $4 to $8 billion in foreign equipment will be required annually through 2000.

US ENERGY SECURITY
- Even with China's increased petroleum imports, world energy markets will only grow at 2-3% per annum, and most of this growth will be from increased demand in the US and Europe.
- Chinese imports will not have a significant effect on energy markets, and therefore will not affect US energy security.

NOTES

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CHINA’S ENERGY

DOMESTIC ENERGY RESOURCES WILL BE ABLE TO MEET OVERALL DEMAND, BUT CHINA WILL NEED TO IMPORT OIL.

World’s fastest growing economy

With Gross Domestic Product (GDP) growing at an average rate of 9.5% for the last fifteen years, China has the world’s fastest growing economy. This rapid pace of growth and industrialization has caused economic strain, which is particularly noticeable in the inability of Chinese commercial fuel production to keep pace with demand. If China allows its commercial energy supply to fall much further behind demand, massive energy imports will be necessary in order to avoid severe bottlenecks in industrial production. Such an energy shortage could impact US energy markets, and possibly affect US energy security if China decides to balance the excess of demand over supply with imports. This paper reports the projection of Chinese commercial energy consumption, so that in conjunction with a production forecast, the likely energy resource shortfalls may be identified.

In terms of overall energy supply, China has the resources to meet rapid economic growth with only modest efficiency gains. However, there will be major disconnects between available and required fuels. Specifically, there will be severe shortages of petroleum and an over-abundance of coal.

Coal substituted for oil where possible

Should China adopt measures to encourage fuel substitution, the fuel imbalances force a dilemma. If imports are restricted to allow domestic prices to reflect the scarcity of oil, the ensuing market dislocations will hurt development; if imports are allowed, the cost will drastically reduce China’s ability to finance badly needed energy infrastructure projects. However the energy supply problems are resolved, energy demand will continue to grow rapidly, led by the industrial sector.

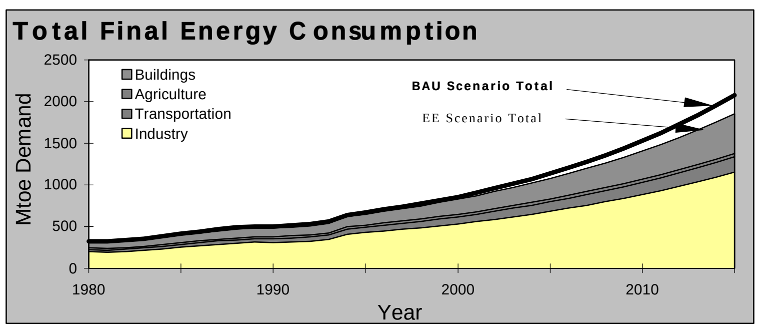
ENERGY DEMAND

While China’s energy consumption is only one-sixth that of OECD countries, population growth ensures significant pressure on energy demand. The combination of an expected population increase from 1.2 to 1.6 billion people by 2030, and rural-to-urban migration with increased living standards, will be accompanied by a shift in demand from coal and non-commercial biomass fuels to cleaner household fuels like electricity and natural gas. Such consumption changes in the residential sector, accompanied by a similar shift away from coal to electricity and petroleum products in industry and increased demand for transportation fuels, have offset China's minor energy exports, and forced this country to become a net importer of oil and natural gas.

Energy demand will double by 2006, and redouble before 2015

Demand growth has been so rapid that total energy consumption more than doubled to 640 Mtoe in the fifteen years before 1994, and is expected to redouble by 2006; and redouble again to 2,077 Mtoe before 2015. Two growth scenarios were projected for this report, an expected growth model called the Business as Usual (BAU) scenario, and a more optimistic Energy Efficient (EE) scenario.

In the BAU projection, total final energy consumption reaches 2,077 Mtoe by 2015, while the EE projection reaches 1,880 Mtoe (2,967 Mtce or 14.9 Bbl oil, and 2,685 Mtce or 13.5 Bbl oil respectively).



INDUSTRY

Industry is largest energy consumer

Currently, industry contributes 55% to the total Chinese GDP and consumes 64% of the total final energy. In the past ten years, most of China's energy efficiency improvements have been in the industrial sector, so assuming that the sectoral GDP continues to grow faster than the national total, as it has for the past decade, the industrial sector will become an even larger part of the Chinese economy. However, the demand projection assumes that energy efficiency improvements will also continue, so that while industry will represent a larger segment of the economy, it will actually represent a smaller fraction of total final energy consumption, down to 60% from 64%. Despite this reduction, industry will remain the largest sectoral consumer at 1,240 Mtoe for the BAU scenario and 1,150 Mtoe for the EE scenario.

BUILDINGS (COMMERCIAL & RESIDENTIAL)

The buildings sector is a combination of the traditional residential and commercial sectors, representing the second largest sectoral energy consumer at 20% of the total final energy consumption, 113 Mtoe in 1993. Most of the commercial fuel consumption is split between electricity and petroleum products, while residential consumption is dominated by cooking and space heating fuels, specifically coal which accounts for 85% of residential consumption.

Residential demand for clean household fuels and electricity increasing

Fuel use in this sector is changing as urban consumers turn away from direct coal use, demanding both electricity and cleaner household fuels like liquefied petroleum gas (LPG). As new power grids are completed and rural consumers begin to buy electrical appliances, demand for electricity will skyrocket. In the urbanized southern coastal region, LPG demand has already forced China to become a net importer of this resource.

Energy consumption in the building’s sector will increase by a multiple of 4.2, reaching 506 Mtoe in 2015.

TRANSPORTATION

Transportation consumption is small, but growing fast

China is unlike other countries because its transportation infrastructure is so limited that this sector, typically a major energy consumer in other economies, makes up less than 10% of the total final energy consumption. However, tremendous increases in road usage is expected to drive rapid growth of this sector.

Most consumption is by road transportation (65%), followed by rail (29%). Transportation energy consumption doubled between 1980 and 1993 to 56 Mtoe, and a quadrupling in the total number of motor vehicles to 12 million by the year 2000, will cause consumption to increased by 3 to 4 times the current value, from 60 Mtoe in 1994 to 259 Mtoe for the BAU and 187 Mtoe for the EE by 2015.

AGRICULTURE

Agriculture is the smallest energy consuming sector, at less than 5% of the total final energy. With labor intensive, low tech manual farming and only minimal mechanization, current consumption is mostly coal at 45%, followed by petroleum products at 38% and electricity at 17%. As the larger farms are mechanized and the sector steps up production to meet the growing food demand, petroleum and electricity will contribute larger shares to the total, but the introduction of energy intensive western farming techniques is not anticipated except on the smallest of scales. Therefore, no significant changes are expected in agricultural demand, projected to reach 41 Mtoe in 2015 for both the BAU and EE scenarios.

ENERGY SUPPLY

Where the people are, energy resources aren't.

In terms of available energy resources, the problems China faces are not from extraction or development, but distribution. The Chinese population is concentrated on the eastern seaboard and in the southeast, while energy resources are everywhere but in those regions. Consequently, distribution infrastructure is critical to Chinese energy development. Transportation bottlenecks are already limiting energy resource shipments. Rail traffic is saturated, forcing the Chinese to abandon upwards of 20 million tons of coal to stockpiles annually. The lack of infrastructure is further inhibiting the development of new petroleum resources in remote western China. There is only one railway into the region, making delivery of both supplies and personnel difficult at best. Unless these infrastructure problems are resolved quickly, increases in resource production will be essentially meaningless because the Chinese will be unable to get the fuels to consumers.

COAL

Coal accounts for 73% of final energy consumption

Coal is the only resource the Chinese have available in abundance. The Chinese lead the world in coal production and this resource currently accounts for 73% of China's total primary energy consumption.

New railway development necessary

The geographic distribution of coal reserves is unfortunate in that 80% are in the northern provinces, while the population lives almost entirely in the south. With coal shipments saturating north-to-south rail traffic, and millions of additional tons of high grade northern coal abandoned to stockpiles annually for lack of transport, the majority of Chinese coal production is conducted in the south, producing undesireable and extremely low grade coal. Despite such limitations, coal remains the only commercial fuel available to offset the growing energy demand.

As the only resource which can be produced in any great quantity, the Chinese will substitute coal for other fuels wherever possible, and continue to build coal burning power plants for the generation of electricity. This means that coal will continue to China's primary fuel source, dominating energy consumption.

OIL

Oil shortages up of 8.8 million barrels per day by 2015

The Chinese will face major oil shortages within the next decade. In ten years (2005) the Chinese will import between 1.2 million and 2.1 million barrels a day depending on domestic production rates. By 2015, the domestic shortfall will have reached 5.8 million to 8.6 million barrels a day.

Production capacity of new oil fields unproven.

Domestic oil production has stagnated in the past decade. The major fields in north-east China have seen zero percent growth since 1985 despite the continuous addition of new wells. Recently, the Chinese have begun to develop potential oil resources in the western desert, specifically a basin the size of France called Tarim. However, despite Chinese optimism and propaganda, the production potential of the region is unproven. This year Tarim will more than double its petroleum output, but still contribute less than 3% to the national petroleum production total. Even China's minuscule offshore industry will produce almost double the Tarim amount.

NATURAL GAS

Natural gas passed over in favor of oil development.

The Chinese have always, and will continue to favor oil over natural gas development. Less than 3% of their potential gas resources have been proven, and development of the proven resources has been slow. In 1990 the Chinese claimed that they would increase natural gas production by 292% before the year 2000. This will not happen. The 1994 production rate was only 9% greater than in 1990. Although gas would seem an ideal residential fuel source, especially in cities, development is simply too expensive. The Chinese will continue to develop oil resources first, and use readily available domestic coal as an alternative to natural gas imports.

HYDROPOWER

China has the largest hydropower generating potential in the world. Steep runoffs from the Himalayan plateau, combined with heavy rainfall in central China, generate many large, fast flowing rivers and literally thousands of smaller ones. China has more than 150,000 small scale rural hydro plants in operation, most with capacities less than 500 kW (capable of powering fewer that 250 houses with four light bulbs and one refrigerator each).

Hydropower resource unable to replace coal fired power plants

Although frequently hailed as a cure-all for the problems China faces in electrical power generation, hydropower is no panacea. Even if all exploitable resources were fully used, hydropower could only contribute 379 GW. This is only less than one third of the projected capacity for the year 2015. Further, most of this generation capacity comes from small sites unsuitable for industrial, or even urban use. Thus, hydropower will likely continue to be the electricity source of choice in rural China, but it will never replace coal burning thermal plants.

NUCLEAR

Nuclear power will never be a major energy source.

Currently, China has only two online nuclear power plants. Both are pressurized water reactors (PWRs). The 300 MW Quinshan plant, designed and built by the Chinese, supplies power to Shanghai. While a French built PWR with two 900 MW reactors in south China’s Daya Bay supplies power to Hong Kong. Although the Chinese have discussed a variety of other nuclear projects, only two plants are actually in the works. One will provide power to the north eastern industrial and shipping region on the Bo Hai Sea, while the second will sit across Daya Bay from the existing plant and supply power to southern China. Between upgrades and the two new plants, China’s nuclear capacity will rise to 8.7 GW by 2010; more than quadrupling the current nuclear capacity, but still contributing less than 2% to the total electrical generating capacity.

There are more than ten additional nuclear plants in various stages of proposal, from feasibility studies to conjecture. However, there are serious doubts as to China’s ability to supply fuel for such a large number of plants.

RENEWABLE RESOURCES

There are regions with abundant solar, geothermal and wind energy resources, but all are remote. China’s sunny regions are in the far western Himalayan plateau, while populated central China is perpetually cloud covered. The geothermal resources, mostly hot springs, are also in the Himalayas, with a few others scattered along the southern coast. China’s windiest areas are in the western desert and remote northern China along Inner Mongolia. Currently, all these resources combined contribute less than half of one percent to China’s energy consumption. It is highly unlikely that this fraction will change in the foreseeable future.

CHINA’S ABILITY TO GENERATE ELECTRICITY

China faces a maximum 24 GW shortfall in annual turbine production

China needs to purchase several billion dollars worth of foreign equipment to meet its stated electricity generation goals. Published State plans show that China intends to add 101 GW generating capacity between 1995 and 2000, or 17 GW added annually. Such development would put the total capacity at 300 GW in the year 2000, but the Chinese can only manufacture 9 GW in turbines domestically per year, leaving a shortfall of 40 GW.

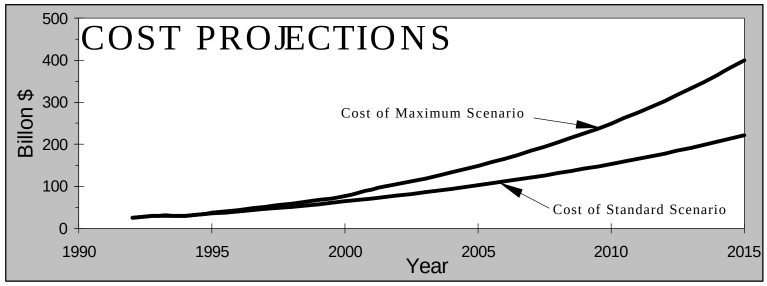
If all other potential domestic manufacturers are included, annual turbine production climbs to 12 GW, still 5 GW short of the requirement. Complicating the situation, the 17 GW annual requirement does not consider refits or upgrades, which if included send the annual capacity requirement up to a maximum of 36.6 GW. To make up this difference China would need to purchase up to 24 GW capacity in foreign generating equipment annually.

China will spend $4 to $8 billion annually on foreign equipment through the year 2000.

In past years, China has bought up to 20% of its generating capacity from foreign suppliers. So while a precedent exists, the scale required makes full refits an unlikely outcome. A more realistic option is that the Chinese will purchase between 5 and 10 GW in foreign equipment for new generating capacity and forego much of the upgrades and refits. This would limit growth, but have the benefit of costing only $4 to $8 billion annually, as opposed to the maximum amount of $19 billion annually to make full refits with foreign equipment.

COST OF CHINESE ENERGY DEVELOPMENT

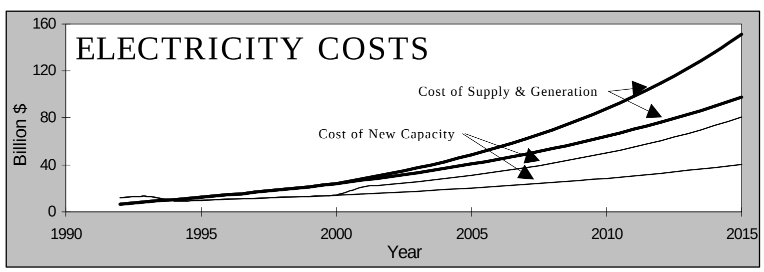
Total energy expenses in 1995 for extraction of coal, oil and natural gas were $13.5 billion, with an additional $12.5 billion spent on electricity generation and $10 billion spent on the installation of new generation capacity. These costs represent a total of $36 billion, or 5.6% of the $643 billion Chinese GDP in 1995.



Chinese spent $36 billion on energy projects in 1995, about 6% of GDP

The costs of the Standard Supply Scenario represent a similar fraction of the Chinese GDP, with values of 6.1% in 2000 and 6.4% in 2015, while the maximum scenario has higher associated costs, representing a 6.9% GDP fraction in the year 2000 and a very high 11% fraction in 2015.

This indicates that the Standard Supply Scenario is a reasonable projection of Chinese energy development, because as a fraction of total spending, the costs are very close to what the Chinese have spent in the past. The ceiling estimate offered by the maximum scenario is less likely, for although the Chinese may have single years of growth at the Maximum scenario rates, they simply cannot afford the cost of sustained development at such a high rate.



US ENERGY SECURITY

Increased Chinese oil imports will have little effect on world energy markets and will not affect US Energy security.

Only one energy resource is likely to have any impact on US energy security: oil. The Chinese petroleum shortage will necessitate increasing import volumes, up from the current (1994) volume of 60 thousand barrels per day, to between 1.2 million to 2.1 million barrels per day by the year 2005, and 5.8 to 8.6 million barrels per day by the year 2015 depending on the rate of domestic resource development.

Although it is possible that Chinese imports might effect US energy security by disrupting the petroleum supply, it is unlikely. As large as these volumes are compared to China's historical import volumes, they are not large enough to destabilize international oil markets. China’s imports are minor compared to the anticipated increases in consumption in the US and Europe. All told, petroleum demand on the world energy market will grow by just 2-3% annually [Clawson]. It is the consensus among analysts that China’s growing imports will not disrupt the international flow of oil, and therefore will not impact US energy security.

CONCLUSIONS

As demand for fuel grows, China will continue to import oil and natural gas.

China will continue to import oil and natural gas, and spend increasing amounts on foreign electrical generation equipment. Domestically, the Chinese face major problems with the lack of support infrastructure needed for continued development of energy resources, especially in increased freight handling capacity. If resource production rates are to increase, these infrastructure bottlenecks must be resolved, else the lack of distribution will, for all intents, cripple the energy industry.

Demand for fuels and electricity will grow in all sectors. Improvements in consumption efficiency will reduce demand from existing consumers, but will not compensate for the demand increases as standards of living rise and the industrial sector continues to grow.

China’s oil and natural gas shortages may be partially alleviated by use of fuel substitution in the industrial and residential sectors, especially as electrical tools and appliances become more common. If coal can be domestically substituted as a fuel on a wide basis, and the remainder exported, China can remain energy self sufficient despite the imports of oil and natural gas.

The certainty of increased coal consumption raises a host of environmental concerns, including the likelihood of sulfur related atmospheric contamination in North America from Chinese emissions. However, since the Chinese have no alternative but to continue utilizing coal as their major energy resource, concerned western countries must convince the Chinese to step up domestic pollution control measures.

ENERGY PRODUCTION

CHINA'S ENERGY DEVELOPMENT IS HAMPERED NOT BY A LACK OF RESOURCES, BUT BY A LACK OF SUPPORT INFRASTRUCTURE

E N E R G Y R E S O U R C E S

A. OVERVIEW

Despite a wealth of raw material, China's physical size and incredible population of 1.2 billion strain available resources. It is easy to consider China an energy poor nation on a per-capita basis, despite the abundance of energy resources.

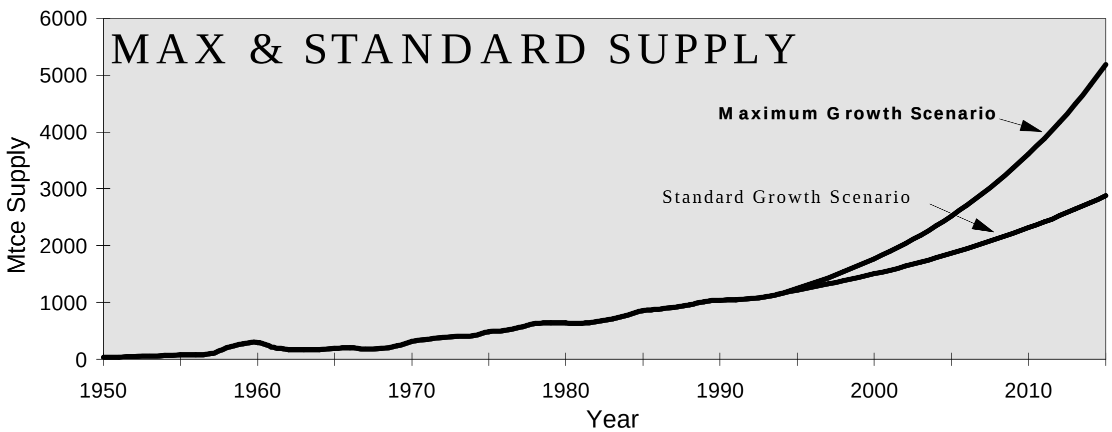
However, China's most significant energy resources problem is not extraction or development, but distribution. Almost without exception, energy resources are in the wrong places: far from consumption centers and hard to reach. Energy resources are found everywhere but in south-central China, where the people are, making transportation and distribution infrastructure a critical part of Chinese energy planning.

For instance, existing rail capacity is insufficient to handle the large volumes of coal being produced at the northern mines. Annually, upwards of 20 million tons of high grade coal is forced into temporary storage at mines in northern China for lack or rail transport. Reportedly, one mining area has more than 60 million tons stockpiled, while power plants in southern China are forced to burn low grade coal from the closer mines.

Other resources fair just as poorly. China's developed oil fields are in the northeast, while new oil prospects are in the far western desert. Due to its expense natural gas has been largely passed over by the Chinese and left to foreign developers, but gas resources are typically linked to petroleum and have the same unfortunate geographic distribution. Populated central China is also far from geothermal sources, as well as perpetually cloud covered and calm most of the year making thermal, solar and wind generation unworkable alternatives. In fact, the only geographically available resource is hydropower, and most of these sites are small, low capacity rivers unsuitable for powering industry.

This means that to supply electricity, energy resources must be transported from the north and west. Coal is brought to thermal plants by rail, tying up 42% of the freight capacity. Oil is sent through long and expensive pipelines. Hydropower has to come from the construction of large dams which raise environmental concerns and occasionally require the relocation of entire districts (the controversial Three Gorges Project is an example of this). Along with the demand for commercial energy, huge volumes of biomass are consumed as fuel for cooking and heating. Again, the even modest per-capita consumption by this incredibly large population makes preservation of forested areas a real concern.

Two scenarios have been generated to estimate energy supply to the year 2015. One is a “Standard Supply Scenario” which is an anticipated minimum production case, and the other is a “Maximum Supply Scenario” which offers a more optimistic production ceiling. Actual production will lie somewhere between the two, probably slightly above the Standard scenario levels[1].



Annual growth in China’s energy resources has varied dramatically over the past twenty years, ranging from a peak annual growth of 21% to an annual low of -12% (a loss) in the case of natural gas. However, despite such swings, overall growth been relatively smooth. The Standard Supply Scenario was modeled by assuming the average growth rate of the past decade would continue, while the Maximum Supply Scenario assumed that the occasional extraordinary production growth rates could be repeated and sustained.

GROWTH RATES BY ENERGY RESOURCE				
GROWTH RATES	COAL	OIL	NATURAL GAS	HYDROPOWER
20 year high	14.32	17.32	20.58	14.29
20 Year low	-2.39	-4.67	-12.04	-9.66
Standard Scenario Rate	4.65	2.93	2.93	5.53
Maximum Scenario Rate	7.50	5.00	5.00	11.00

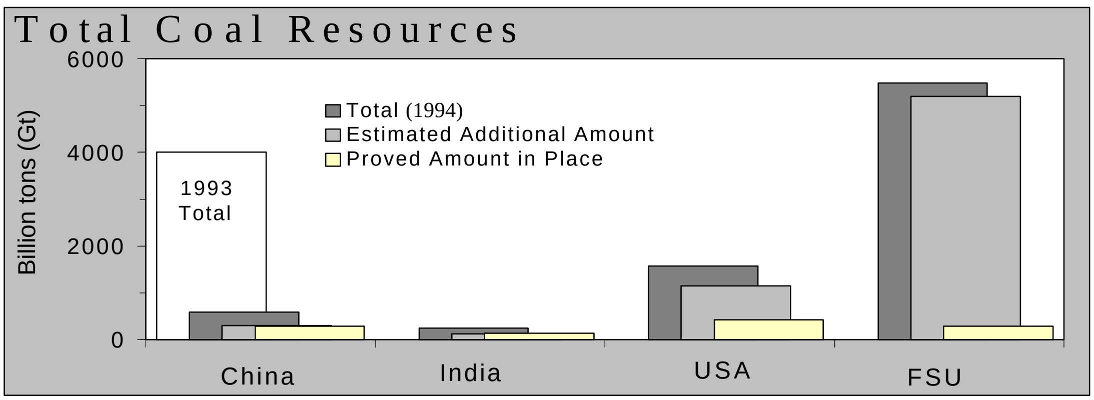
B. COAL

[1] Standard scenario represents spending levels at 6% of GDP, near current costs. See “Costs, Finance & Trade” in this section under ‘Total Costs to Supply Energy Resources & Electricity”; see also Summary, Section I to see how this scenario matches demand curves.

Implementation of Chairman Mao's "industrial progress" plan required increases in steel production, rail transportation and electrical power. All of these required coal. It is fair to say that coal literally powered Chinese industrialization, and today continues to dominate Chinese energy policy.

In 1993 the Chinese consumed 1,139 million tons (Mtons) of raw coal accounting for 73.1% of the nation's total primary energy consumption [CED'95 IV-1.3]. In the past decade consumption has grown faster than total energy consumption, with growth rates of 5.9% and 5.2% respectively, indicating that coal continues to be the most accessible and popular energy source [CED'95 IV-1.4].

1. Coal Production



Coal bearing sediments cover over 5% of Chinese territory (550,000 km^2) with deposits in every province. Total coal resources have been estimated by the Chinese at 3.2 trillion tons but Chinese numbers must be weighed carefully. The Ministry of Energy once estimated total coal resources at 9.6 trillion tons, more than the global total [Smil p.31]. Even in 1987 (published 1993), through the use of unique and unrealistic classification schemes, Chinese estimates placed total coal resources[†] at 4.0 trillion tons with recoverable reserves[‡] totaling more than 167 billion tons [CED I-7]. Current World Energy Conference (1990) figures, using western classifications of Proved Amount in

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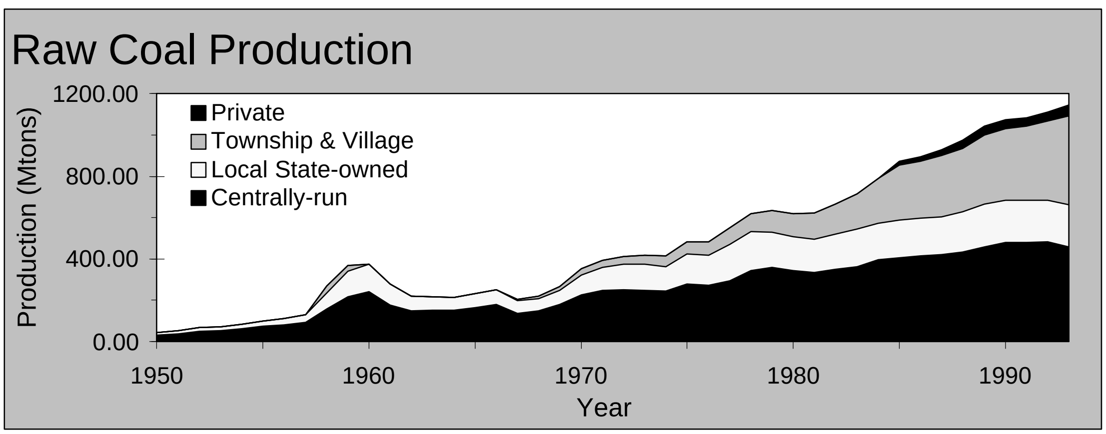
[†] Unless otherwise noted, in this report "total resources" refers to the sum of World Energy Conference *Proved Amount in Place (PAP)* and *Estimated Additional Amount in Place (EAP)* numbers. *Proved Amount in Place (PAP)* is defined as "the [amount] that has been carefully measured and has been assessed as exploitable under present and expected local economic conditions with existing available technology". *Estimated Additional Amount in Place (EAP)* is defined as " the indicated and inferred [amount] additional to the PAP. It includes estimates of amounts which could exist in unexplored extensions of known deposits or in undiscovered deposits in known fuel-bearing areas as well as amounts inferred through knowledge of favorable geographic conditions. Deposits whose existence is merely speculative are not included".

[‡]"Recoverable Reserves" in this report refers to the British Petroleum Category of Proved Reserves, defined as "those quantities which geological and engineering information indicate with reasonable certainty can be recovered from known reservoirs under existing economic and operating conditions". In most cases, this is slightly lower than the *Proved Amount in Place* as described above.

Place (PAP) and Estimated Additional Amount in Place (EAP) drop that total by 85% to 591 billion tons total, with recoverable reserves down 32% to 114.5 billion tons.

Despite such drastic changes in resource estimates, China still leads the world in actual coal production at 1116 Mtons, with the closest followers being the US at 823 Mtons, and the former USSR at 412 Mtons (1994 data). China has 2242 coal mines, with an average annual mine capacity of 100,000 tons. Just under half of production is generated by state-owned mines, with the largest controlled by the China National Coal Corporation (formerly the Ministry of Coal and Industry). State mines average an annual 9.6 Mtons output, with the largest producing more than 30 Mtons. Coal produced at Ministry mines is rationed, distributed at a subsidized price to State enterprises, then what remains is traded at market prices. In areas where coal is available in quantities too small to merit the attention of the central government, state-owned but locally supervised small and medium sized mines are operated to meet local demand. These smaller local government mines contribute about 20% to China's coal production.

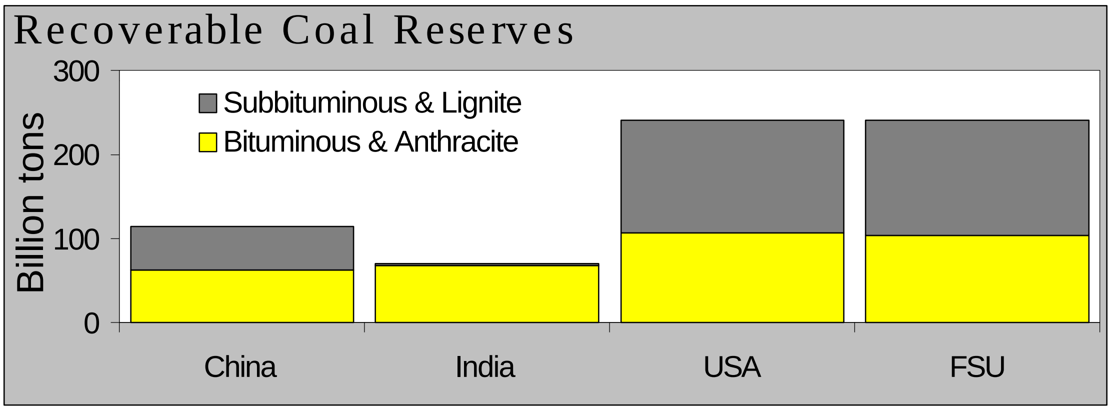


The remainder of coal production is conducted by privately owned, small scale mining companies. In the late 1970s the Chinese government passed several economic reforms allowing private ownership of mines as a means of increasing production with minimal state investment. Since then these rural-collective mines (both private and village owned) have accounted for almost all growth in coal production [OSD p.II-17].

2. Types of Coal

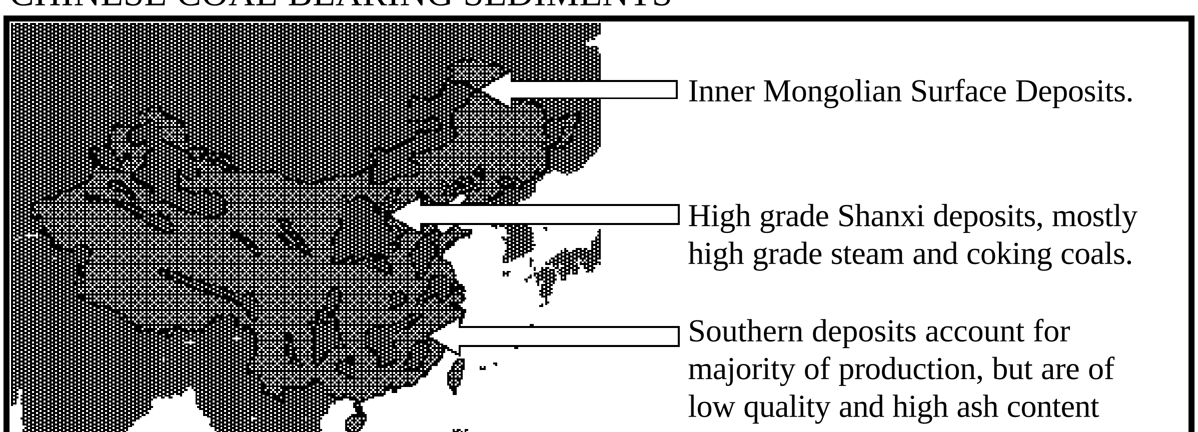
The most prominent reserves of hard coal are bituminous (high grade steam and coking coals) with less than 1% sulfur content. The Ministry of Energy estimates its coal reserves at 79% bituminous (59% steam coal and 20% coking coal), 6% anthracite and 15% lignite [CED p.I-7(d)]. Compared to other countries Chinese coals have a high percentage of anthracite with high ash/heat and low sulfur/heat ratios.

In general, the high quality reserves are found in northern China, where eighty percent of the total reserves are found. The Shenfu field in northern Shanxi produces high grade coal with low ash content (6 to 7 percent before washing) and low sulfur content (0.5 to 0.6 percent) making it very attractive on both domestic and international markets [Dorian & Fridley, pp. 60-61]. Unfortunately, the majority of mined coal comes from the south, and has both a low equivalency rating (tce/ton) and often a very high sulfur content, up to 20% from some mines.



Steel production has historically been seen as the cornerstone for industrial development, and in the past Chinese Ministry officials have demanded large volumes of coking coal to fuel steel production. However, politically motivated estimates for steel industry growth were greatly inflated and in 1988 only 89 of the 463 million tons of coking coal produced were used for coking [OSD, p.II-19]. With export capacity limited, most of this high grade and expensive coal was consumed domestically as steam coal or household fuel. Such non-industrial consumption of export quality fuel was a waste and since then the percentage of coking coal extracted from bituminous coal seams has dropped from 63% to 20% in an effort to preserve the resource. Globally, high grade coking coals are relatively rare, so their use in China as a boiler fuel is not desirable.

CHINESE COAL BEARING SEDIMENTS



Source: *Energy in China's Modernization*, Vaclav Smil

3. Mining and Processing

Compared to those found in the US or former Soviet Union (FSU), Chinese mining conditions are unfavorable. Coal seams are thinner, deeper and further from consumption centers making both extraction and transportation expensive.

Ministry owned mines collect approximately 11% of their output from seams thinner than 1.3 m, 43% from 1.3-3.5 m seams and 46% from seams thicker than 3.5 m. By comparison the average US seam is noticeably thicker at almost 5 m [OSD p.II-19]. However, Chinese seams are relatively flat and accessible, with only 5% having difficult or steep inclines. The high organic content of Chinese coal, responsible for the high ash and sulfur contents, leads to mine gas accumulation. Almost half (45%) of the operating mines have a high potential for methane accumulations and explosions [Smil, p.32]. Coal production is further hampered by a lack of surface deposits. Production from relatively inexpensive surface mines is only 4%, compared to 60% in the US and 40% in the former USSR [OSD p.II-20]. Most of China's proven reserves lie between 300 and 500 m depth and require multiple deep shafts to work a seam, making operations capital intensive.

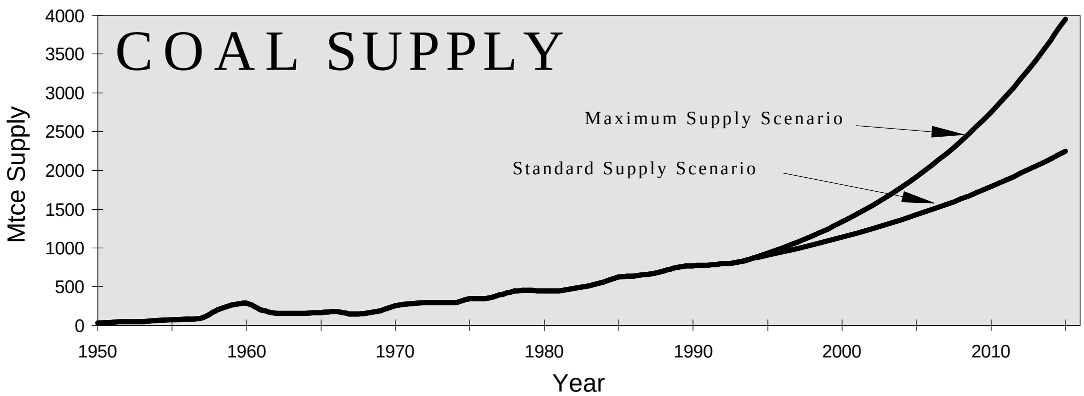
Because the mines themselves are so very expensive, China has been slow to mechanize. Even in the state supported Ministry mines, in 1988 only 31.4% had fully mechanized processes, and of the remainder only 58% had mechanized extraction. The smaller, lower budget, locally supervised mines have a much lower mechanization rate. In many rural areas extraction is done manually. This makes Chinese labor productivity quite low. Ministry owned mines (with 58% mechanized extraction) average 1.1 tons per miner-shift, while the US average is 23 tons [OSD p.II-20]. If the rural mines were included in this average, the Chinese statistics would be considerably lower.

In the past decade international pressure and domestic awareness have forced the Chinese to pay closer attention to the environmental consequences of heavy coal use. Of great concern is the release of sulfur from thermally inefficient and environmentally damaging unwashed coal. In response, the Chinese have begun shifting mining operations to the northern provinces where higher grade coal can be mined and some development of coal washing facilities is underway. However, treatment is expensive and the government has balked at the investment required to treat the volume of coal consumed annually. Currently only 17% of Chinese coal is washed, and more than 80% is consumed with no treatment at all [CED II-10]. Cost analysis of the increased energy per ton, improved end use combustion, reduced pollution and decreased transportation costs has encouraged China to wash coal for those industries which require high grade fuel for industrial processing, but other industries and consumers must do without. Present washing capacity is 190 Mtons per year (1988) with 170 Mtons actually washed; 70% of this capacity is devoted to coking coal for the steel industry.

4. Planned Development

China anticipates a national production capacity, not including rural collective mines, of at least 1400 Mtons per annum by the year 2000. 40 Mtons of current production capacity will be non-productive by this time, requiring not only an increase in efficiency at existing mines but expansion into new beds.

Much of the planned development involves surface mining in the northern provinces of Shanxi and Inner Mongolia. China hopes to use its limited surface reserves to meet the immediate demand in electrical power generation for steam coal. The six large surface mines operating in Shanxi-Mongol region expect an annual production of 280 Mtons by the year 2000. To meet such goals production will be stepped up dramatically. For instance, the Shengfu-Dongsheng surface mine's current output of 30 Mtons per year of steam coal is expected to double to 60 Mtons in the next five years [OSD p.II-21].

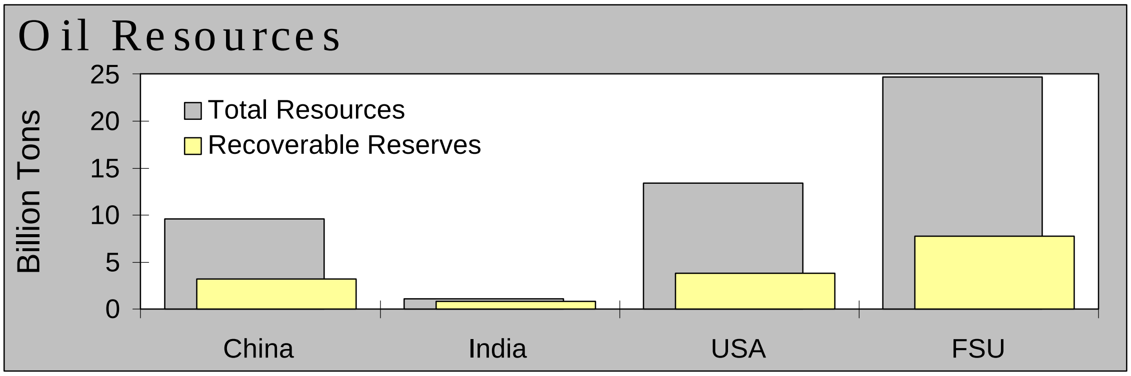


In the past decade, coal production has grown at an average of 4.65% annually. The Standard Supply scenario projects this rate out to 2015, assuming that growth in Chinese coal production will not fall below this. Note that the State capacity prediction of 1400 Mtons (999 Mtce) only corresponds to a growth rate of 2.5%. The difference between this rate and the Standard rate is accounted for by the production of small private and rural-collective mines not included in the State estimate. A ceiling rate was calculated for the Maximum Supply Scenario from the best five years for production capacity increases, resulting in a maximum annual average growth rate of 7.5%.

## C.	PETROLEUM PRODUCTS

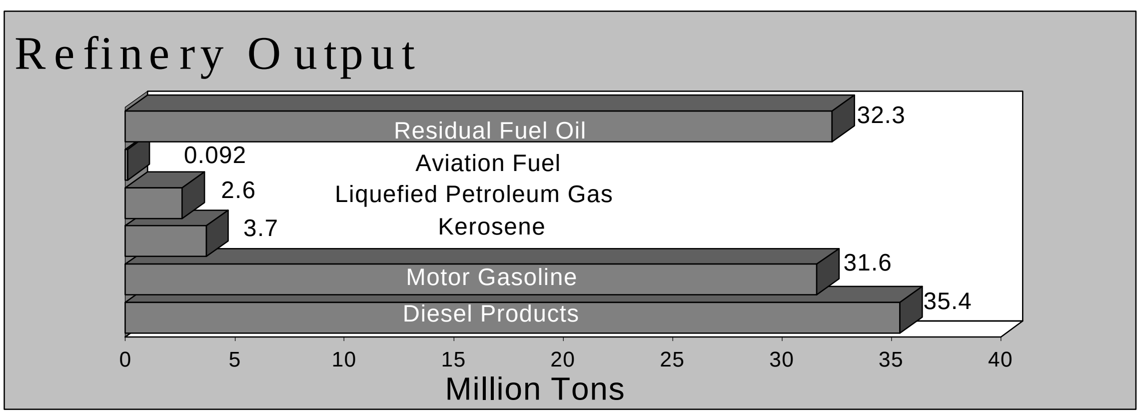
In 1957, sixty percent of China's oil was imported. Development of oil resources in the 1960s and 70s allowed China to experience an oil "boom" with 25% annual growth and to achieve a measure of energy autonomy. With petroleum production growing so rapidly, China began exporting oil, peaking at 6.21 Mtons in 1985. Unfortunately as domestic consumption continued to increase while production stagnated, the level of exports dropped and in 1993 China again became a net oil importer [CED t.VII-1].

The quality of the initial petroleum reservoir surveys in the 1950's and 60's, accompanied by hype and blatant exaggeration by the State led to disappointments in both industry growth and annual production yield. One early statement by the Ministry of Energy claimed reserves in excess of 50 billion tons, putting China ahead of Saudi Arabia. Since the 70's, much of the exploration (especially offshore) has been conducted by foreign companies resulting in far more modest reserve estimates. Current estimates are 9.6 billion tons for total resources † with recoverable reserves estimated at 3.3 billion tons ‡ [CED p.I-8].



1. Oil Production

Despite grandiose claims, China has been unable to produce crude on a scale approaching the old State predictions. Production in existing fields is disappointing, and many alternative fields in the western deserts and offshore in the South China Sea are being developed in an effort to boost production.



The first Chinese oil was discovered in north-eastern China's Songliao basin near Daqing in 1959. These now heavily developed fields were the backbone of China's oil industry, generating a 23.9% annual production growth rate even with obsolete technology from 1968 to 1976. However, maturation of the field, severe under-investment and a lack of technical expertise caused a drop in production in 1977. With aid from foreign companies and an infusion of western technology, production rates climbed slightly in the early 1980s, but almost immediately again stagnated. Since 1985 Daqing has seen 0.0% growth

† World Energy Conference sum of PAP and EAP numbers.
‡ BP category Proven Reserves.

in output, even with the addition of multiple new drilling sites. As a whole, the Chinese oil industry has seen only 1.4% growth since 1990.

In 1994 China produced 147 Mtons of crude, with almost 5 Mtons from off-shore wells. China has 33 medium and large oil refineries (1988) with a 145 Mton distillation capacity. 1993 throughput totaled 131 Mtons with a production total of 117 Mtons [‘93UN, t16]. Refineries produced 35.4 Mtons of diesel products, 31.6 Mtons of motor gasoline, 3.7 Mtons of kerosene, 2.6 Mtons of liquefied petroleum gas and 92 thousand tons of aviation grade fuel with 32.3 Mtons of residual fuel oil [‘93 UN, t26].

2. Crude Oil Characteristics

Chinese crude is heavy and found in small complex geological structures. Consequently reservoirs are small and thin, containing high density crude that reduces cavity pressure and requires artificial displacement for extraction. Ninety percent of the Chinese wells require early secondary extraction and use water injection to pump crude. These physical constraints, combined with generally outdated technology push China’s recovery rate down to about 27%. However, cheap equipment and inexpensive labor allow oil to be extracted at competitively low prices despite these difficulties.

3. Planned Development

Offshore exploration led to the installation of a few platforms in the South China Sea but production has been disappointing. More promising is the development of the Tarim basin in western China’s Xinjiang Province.

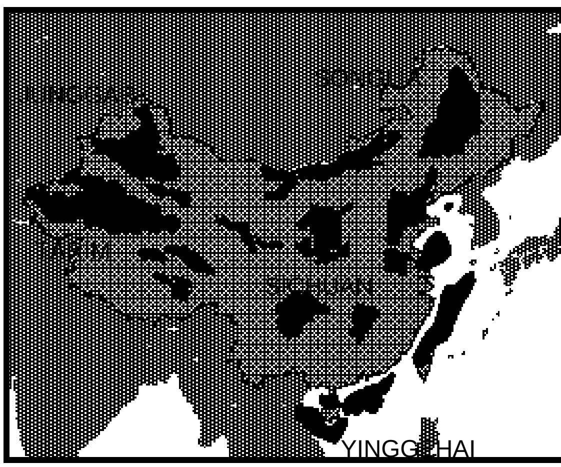
Enthusiastic oil companies once estimated the reserves of oil and gas in Tarim (about the size of France) at up to 10 billion tons. Most of those estimates, especially the older ones from the late ‘70s, were based on extrapolation from existing foreign basins of similar stratigraphy, but this assumption that China’s resources will bear out like those in other countries is not yet supported by any evidence. Unless, of course, one believes the tee-shirts worn by Tarim drillers which read “The Great Hope of China’s Oil Industry.” Unfortunately several years of publication in the popular press and the Ministry of Energy’s *Yearbook of Chinese Energy* have allowed the Tarim myth to be perceived as reality.

Even if the basin does not have reserves as large as the State would like, development in Tarim is currently China’s only hope of minimizing oil imports. Production rates are climbing but there is still some doubt about the regions total production capacity. The recent surge in production can be directly linked to the expansion of the single railway line into the region, allowing the construction of new drilling stations. Output surged from the 1990 total of 150,000 tons to 1.95 million tons in 1994. 1996 production is expected to approach 5 million tons, more than double the 1994 total, but again, this growth is large only because prior to 1994, there was almost no development of the region. Further, though much publicized, the estimated 1996 total of 5 million tons is only 3% of the expected ’96 national production total, and cannot compare to the output of the Daqing or Shengli fields which produced 56 and 31 million tons respectively in 1994. Even China’s fledgling offshore industry is expected to produce almost double the Tarim figure in 1996, with a total of 8 to 10 million tons [Reuters 300812Z,].

The only credible estimates for total production capacities are based on current production rates, plans for expansion and confirmed reservoir discoveries. The 1986 global study by the *Oil and Gas Journal* puts China’s recoverable reserves at 2.6 billion tons [‡] [Smil. p.37]. This has since been upgraded by DOE to 3.2 billion tons [‡][2], but is still considerably lower than Chinese Ministry figures.

This rejection of Ministry figures is not an indication that China’s petroleum industry has no future. The three major fields being worked in the Tarim basin have potential and are the country’s most important oil development area. There are problems in that western China has very little transportation or communication infrastructure, making both construction of refineries and transportation of oil out of the region difficult. Projects currently underway to ease these difficulties include pipeline construction and railway expansion. Currently 60-70% of Xinjiang’s rail traffic is devoted to oil transportation. The recently completed expansion of the Lanzhou-Urumqi line to dual track will partially relieve the bottleneck, but a 1,000 km pipeline from Xinjiang to the refineries in Sichuan (central China) is under construction at a cost of ¥ 5 billion to further alleviate strain on the rail system.

CHINESE HYDROCARBON BASINS



Ailing production in north-eastern China is expected to be replaced by new oil sources in the western desert, specifically a basin about the size of France called Tarim

Source: *Energy in China’s Modernization*, Vaclav Smil

The greatest threat to Chinese oil production is the very real possibility that the Daqing reserves in Songliao may soon be exhausted. The decrease in production during the late 70s and early 80s only leveled off (and has remained at 0% growth since 1985) because oil companies began drilling layers as thin as 0.2-0.5 meters. More than 50% of Daqing’s recoverable reserves have already been extracted, and those remaining have a high water

‡ BP category Proven Reserves.

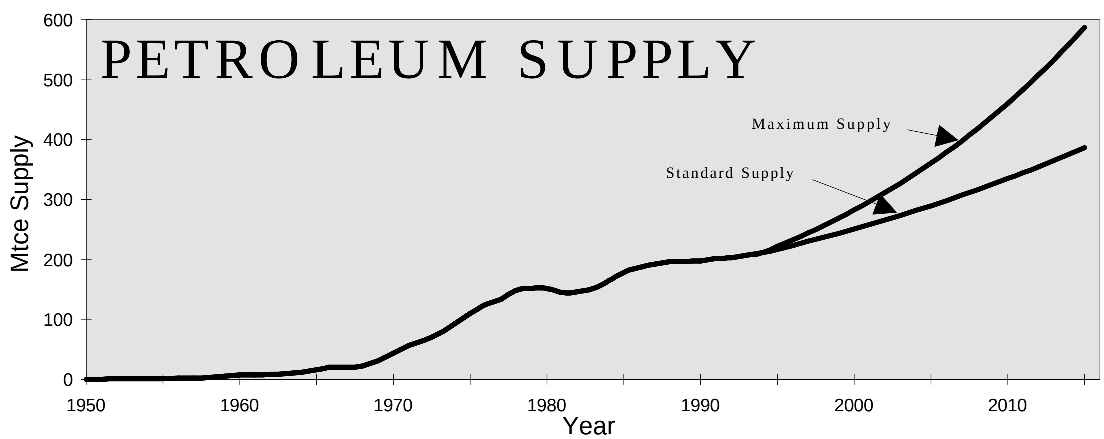
‡ BP category Proven Reserves.

2 As quoted in LBNL’s *China Energy Databook*, p. I-7

content (>70%) due to pressurized injection as a secondary recovery technique. Interviews with Daqing area residents reveal that to sustain production, pumps have been installed in playgrounds, parks and even small strips between houses.

In addition to the obvious expenses of constructing new drilling stations and refineries if Daqing fails there are many additional associated costs. The existing Daqing fields are near China's industrial centers, so oil transport has never been a major issue. However, the shift of industrial growth to south-east China and the Yangtze river basin will require either new pipelines or alternate oil transport methods. This need may be partially met by the new pipeline from western Xinjiang to central Sichuan, but further development of either this pipeline or the closer offshore platforms will be necessary.

The US State Department estimates that China could face up to an 80 million ton shortfall by 2000, and quotes unpublicized Chinese Ministry estimates of a 50 million ton shortfall. Our projection estimates the Chinese shortfall at between 42 and 64 million tons in the year 2000, equivalent to 817 thousand to 1.3 million barrels per day (see Summary). These figures are a closer match to the Chinese estimates than the slightly higher State department figures. In either case, the shortfall will spur new development of domestic Chinese oil resources.



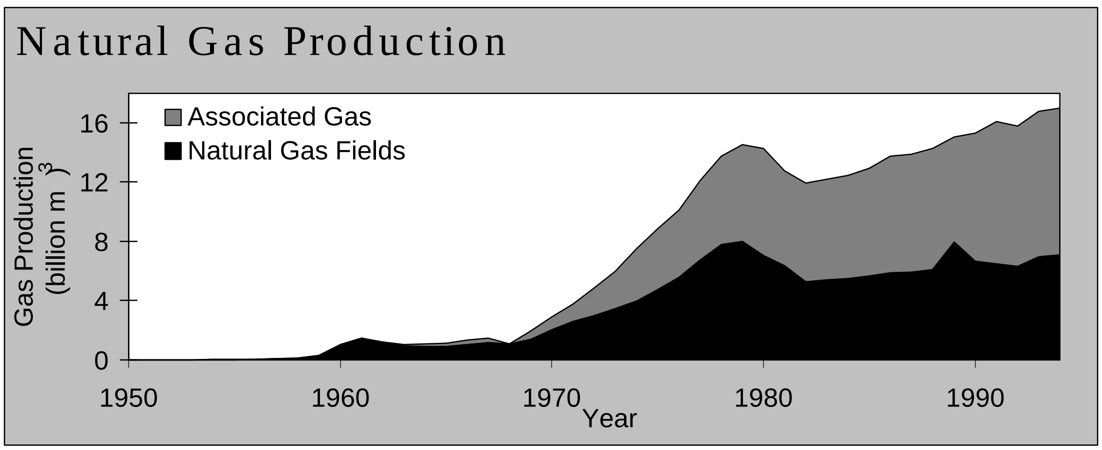
For the Standard Supply Scenario, a growth rate of 2.93% was used, with a ceiling rate of 5% used for the Maximum scenario.

D. NATURAL GAS

China produces very little natural gas and output growth has recently declined. Petroleum has always, and will continue to be the Chinese priority. In other countries, this minimal growth would be indicative of small reserves, which is not the case in China. However, the growth may increase with new discoveries offshore. The 1983 Atlantic Richfield Company's discovery of natural gas off Hainan was a major boost for Chinese reserves and gave production rates a significant boost. It is possible that further exploration will yield similar results but little has been done so far. As of 1992 only 2.6% of the estimated gas reserves had been proven [OSD p.1-5].

1. Gas Production

Current estimates credit China with 10.0 trillion m^3 in natural gas resources † (13,300 Mtce) including 1.7 trillion m^3 in recoverable reserves ‡ (2,300 Mtce) [CED t.I-1,3]. In 1994 16.97 billion m^3 were recovered, with forty percent of that coming from the Sichuan fields in central China [CED t.II-1]. The Chinese have emphasized oil resource development, rather than gas, and consequently have an gas:oil recovery ratio of 0.107:1 which is very low when compared to the nearly 1:1 ratio in the US and other major oil producing countries [OSD p.II-25]. Gas recovery requires more sophisticated technology and heavier capital investment than oil and therefore has been largely passed over by the Chinese.



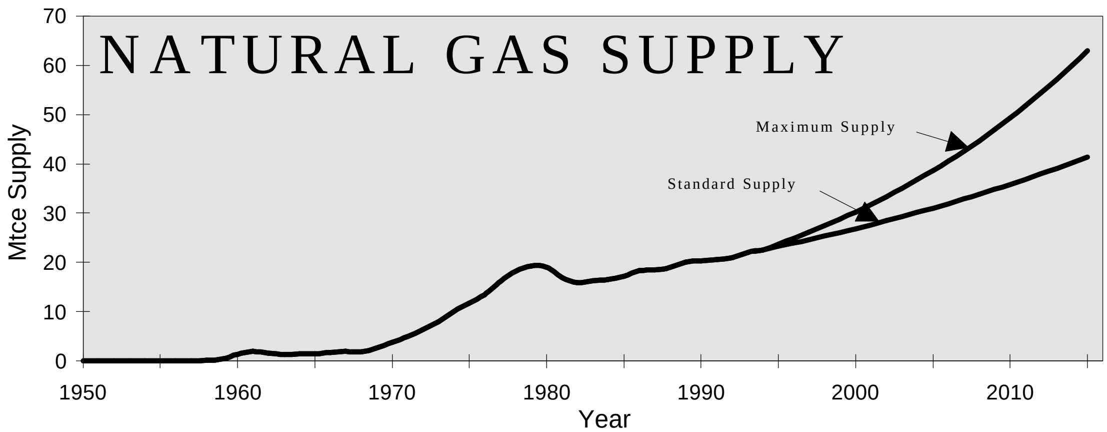
It is possible that the Chinese claims of huge gas reserves offshore may be born out, but to date only one platform has met with any real success. The Atlantic-Richfield Company's (ARCO's) 1983 discovery of natural gas in the Yinggehai Basin off Hainan in the South China Sea led to the development of the only offshore platform (Yacheng 13-1) which seems to be living up to the Chinese promises. In January 1996 ARCO announced that Yacheng 13-1 was ready to enter commercial operation, with an expected output of 7.9 million m^3 daily. The gas will be processed off-shore and fed to the mainland via a 1050 kilometer sub-sea pipeline, the second longest in the world [ED v24 n7]. The Yacheng field has recoverable reserves of 85 million m^3, while the entire Yinggehai basin has an estimated 90 billion m^3 total natural gas resources [ED v24 n7, Owen, p.36].

2. Planned Gas Development

The enormous cost of natural gas projects, about $1 billion per million tons annual capacity, will continue to limit development of this resource [Reuters R040646Z, Jul 95].

† WEC PAP and EAP figures.
‡ Adaptation of BP category "Proved Reserves"

State projections estimate a total of 60 billion m^3 annual production by the year 2000. This would be a 292% increase from the 15.3 billion m^3 1990 total. Declining onshore production may be offset by offshore stations, but many more extraction sites need to be developed if this goal is to be reached. As of 1994 production has increased by less than 11%, making the claimed 202% increase totally unattainable. Further, the 1993-2000 State plan[3] listed only two major gas development projects. The first project calls for onshore reconstruction of the old gas fields in central China's Sichuan province and laying new pipelines. These improvements are expected to yield an additional 2.5 billion m^3 per year. The second project was the development of the Yacheng offshore gas-field, with an expected increase in output of 3.25 billion m^3 per year. The Yacheng platform did begin commercial operation in January '96, but onshore development has been much slower. Even if successful these two projects will increase gas production by only 5.75 billion m^3 (5.35 Btce), leaving China more than 40 billion m^3 short of its goal. This slow development is in complete contradiction to stated production goals, calling into question China's financial, rather than rhetorical commitment to natural gas development.



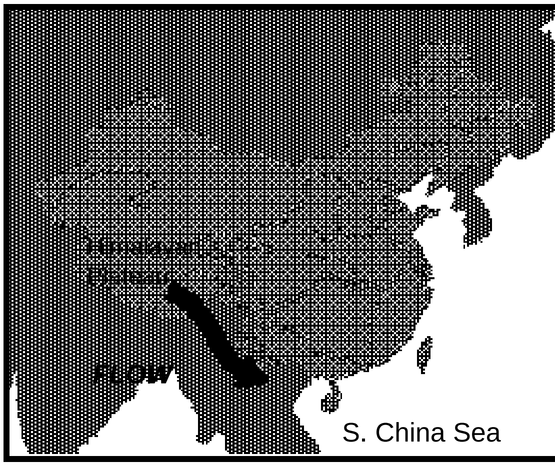
For the Standard scenario, the past decade's average growth of 2.93% was used, while a higher rate of 5% made the Maximum scenario. The actual "high" rate as calculated for natural gas was only 4.48%, but this was increased to match the petroleum industry's maximum growth rate of 5%. This may be interpreted as a continued reliance on petroleum associated fields for gas production, so that as oil production increases, so will natural gas.

E. HYDRO

China has the world's largest hydropower resource. Large rivers originating on the world's highest plateau and the northern edge of the Himalayas in western China have steep gradients and deep valleys, allowing the construction of large hydropower stations.

[3] *The Compilation of Major Technology Introducing Projects of the People's Republic of China from 1993-2000*

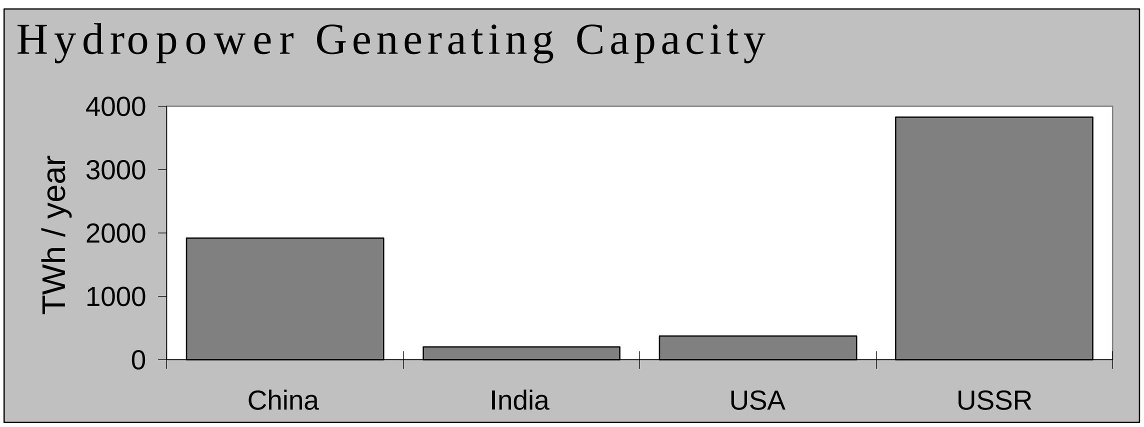
CHINESE RIVER FLOWS



A steep gradient from the Himalayan Plateau to the South China Sea, when combined with heavy rainfall in central China, provides the world's largest potential hydropower generating capacity.

Unfortunately, most of these rivers are small, and unsuitable for powering either industry or urban centers.

Additional monsoon season rainfall in the southwestern regions generates enough water volume to power small scale local hydro plants year round. There are more than 50,000 rivers with drainage basins larger than 100 km^2, and some 1,200 of these have catchments larger than 1,000 km^2. Altogether these rivers carry some 2,640 km^3 of water annually, placing China fifth in the world for water volume [Smil, p.24]. In terms of generating potential China ranks first. The steep gradients and narrow valleys from the western plateau drive the water at relatively high speeds giving China a total of 680 GW of potential generation [4], with 55% or 379 GW of that exploitable (1977-1980 survey data) [OSD p.1-6 & Smil p.24].



Despite these tremendous resources, construction difficulties have prevented the Chinese from making use of many major rivers. The best sites are often in remote and mountainous locations making hydro-plants expensive to build and requiring costly long

[4] Corresponds to WEC category of Exploitable Capability, defined as "the amount of Gross Theoretical Capability that can be exploited within the limits of current technology and under present and expected local economic conditions." Gross Theoretical Capability is "the annual energy potential available in the country if all natural flows were turbined down to sea level or to the water level of the border of the country... with 100 percent efficiency from the machinery driving the water works." Includes output from hydropower stations of all sizes.

distance transmission lines. At present, only 4% of the exploitable hydro resources are being used to generate electrical power (1990) and drought conditions from 1993 to July of 1996 caused a drop in production from these [EinC, p.20].

As with China's other resources, hydropower is not evenly distributed. The southwestern areas dominate with 68% followed by the south-central and central regions. The eastern shore and northeastern industrial areas, where electricity demand is highest hold only 6%.

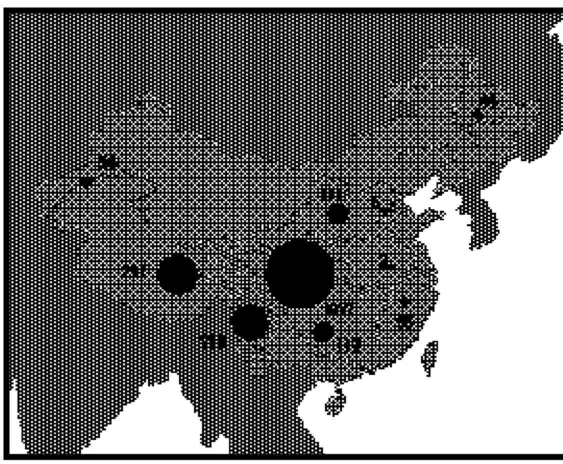
Hydropower has been essential for the generation of electricity in China's rural areas. Small hydro stations power more than 40 local inter-county hydropower grids. In those counties where rural electrification has been tested, 309 started out using hydropower resources and 215 of these have reached a preliminary stage of rural electrification. This growth in installed rural capacity has quadrupled the industrial and agricultural gross output value as well as individual farmer's income in these test regions.

1. Hydro Use

Total annual generating capacity of China's 379 GW exploitable hydro resources amounts to 1,950 TWh. The generating potential is dominated by 33 medium to large sites with a 2 GW or greater capacity, accounting for 50% of the total.

China's is unique in its high percentage of small hydro plants. The steep gradient running from the west to the southeast, combined with heavy seasonal rainfall in central China, generates flow rates sufficiently high that even small rivers can be used for local power generation. Thirty seven percent of the country's hydro capacity comes from plants smaller than 25 MW, and only 41% comes from plants with capacities greater than 250 MW.

CHINESE HYDROPOWER GENERATION



Although runoff grades are steeper in the mountainous south west, it is the heavy rainfall in Central China which is responsible for most of the potential hydropower resources.

Numbers in GW generating capacity
source: *Energy in China's Modernization*, Vaclav Smil

In the past decade, most of the hydro resources developed have been low capacity. Local communities not served by the main power grids built their own small hydro-powered grids. At the end of 1983 there were 76,600 small plants (3,400 with an installed capacity between 500 kW and 12,000 kW, and 73,200 with capacity less than 500 kW) generating 19.9 TWh of electricity [EinC p.20].

2. The Three Gorges Project

In October 1995 construction began on what will become the world's largest hydro-electric generating station. The Chinese are damming a major river, the Yangtze (or *Chang Jian*), with a concrete and steel dam 606 feet high and 7,640 feet wide in the three Gorges region. It will raise water levels 330 feet for 370 miles of river. The dam itself will contain twenty six 500 MW turbines and three deep water locks which will allow heavy shipping to penetrate deep into the mainland.

If it operates as intended, the dam will be able to provide badly needed electricity to energy poor central China. The dam will reduce the seasonal flood risks of the type which claimed more than 300 lives in the spring of 1996. Additionally, the new shipping routes will reduce the need for rail traffic while allowing inland China to develop an industrial base.

However, opponents of the dam claim that none of these thing will happen. Concerns range from the political, including the relocation of 8 million people, to environmental concerns over the loss of cropland and destruction of the gorge's ecosystem. Further, the Yangtze is heavily silted, and some analysts have reported that between siltation [5] reducing the throughput of the dam and seasonal flow variations that the guaranteed generating capacity will be reduced 77% to 3 GW [6] from 13 GW. Other complaints range from general skepticism about the quality of the construction, to fear than an earthquake will send the overhanging cliff face crashing down onto the dam.

Recent floods with death tolls in the thousands and severe property damage on the Yangtze will probably give increased political clout to those in favor of damming the river. In the meantime, despite criticisms, construction continues and the project is expected to be completed in 2009.

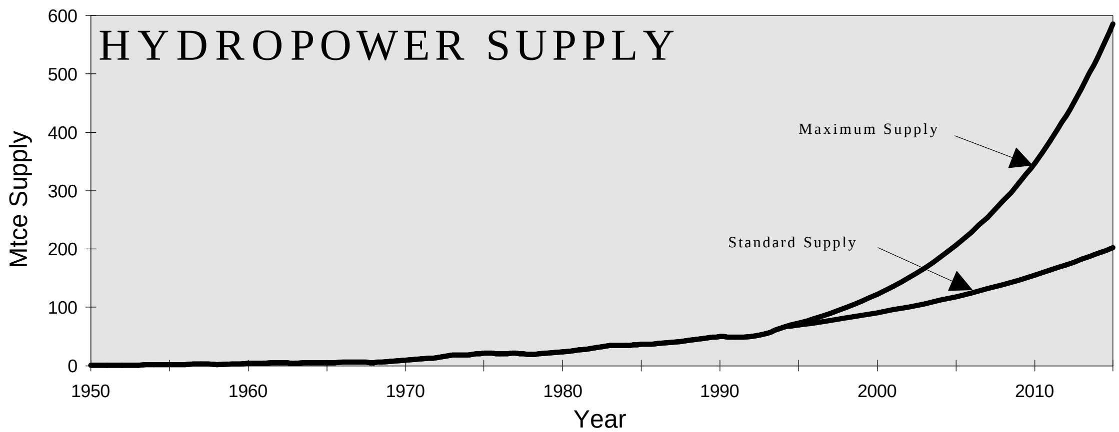
3. Planned Development

China intends to reach a 300 GW total electrical generating capacity by the year 2000 (adding 117 GW to the 1995 total). In addition to the Three Gorges Project, there are an additional ten proposed hydro projects in Jinsha River totaling 75 GW (feasibility studies

[5] Siltation is the build-up of river sediment (dirt) upstream of the dam. It is possible that the dam will reduce the river's flow rate sufficiently that silt which is currently carried down stream will instead be deposited at the dam.
[6] The source does not offer a rationalization for this low number. However, the 3 GW figure comes from a 38 day field inspection by the Economic Construction Group, at the request of the Sixth National Political Consultative Committee. The investigative team included a former vice minister of the State Planning Commission, the adviser to the State Economic Commission and the Vice Minister of Commerce.

for the first two of these expected early ‘96) and any number of smaller local projects [IWPDC, p.18-20].

Although the State seems to be emphasizing large scale hydropower projects, the number of smaller local sites continues to grow. It seems that China is willing to let local communities build their own generating plants while the government focuses on supplying power to the growing industrial centers. However, a Siemens spokesman said “we cannot confirm a shift of interest from large scale to smaller projects. Lower total investment or shorter construction time, however, would be in favor of such considerations” [IWPDC, p19].



For the Standard supply scenario, the ten year average growth rate of 5.53% was used, with an 11% rate used for the Maximum supply scenario. This maximum rate would make hydropower the fastest growing energy resource in China. It should be noted, however, that although the Maximum Supply Scenario does provide a definite ceiling, growth is much more likely to be near the Standards scenario level. The Maximum scenario’s projection of 585 Mtce electricity generation in the year 2015 is equivalent to 321 GW of generating capacity. This represents 85% of China’s 379 GW total exploitable hydropower resources. If the Chinese did somehow manage to install hydropower at the Maximum Supply Scenario rate, growth could only continue for one additional year until 2016 when all of China’s exploitable hydropower resources would be in use. As this is unlikely to occur, the Standard scenario growth rate leading to just 29% use of the exploitable resources is a more reasonable projection.

F. BIOMASS

“No other resource is so contrastingly dichotomous as the country’s biomass: so critical for everyday rural needs yet so ubiquitously scarce, its potential production so large yet the current sustainable harvest so low” [Smil, p.19]. Biomass supplies 90% of the total energy consumption to some 800 million peasants in China’s countryside [EinC, p.21].

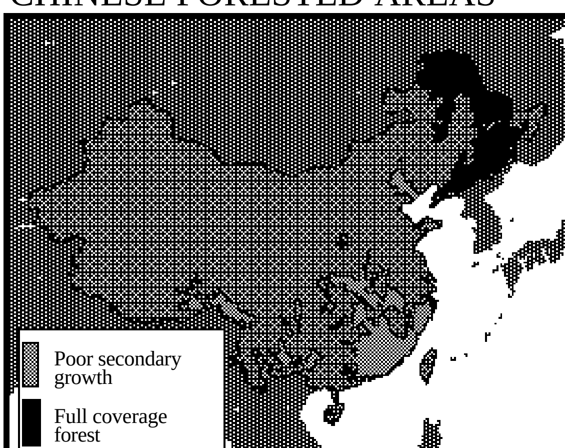
China's phytomass[7] resources measure at 30 billion dry tons (roughly 15 Btce) with a net annual production of no more than 4.3 billion tons [Smil, p.19]. This represents about 3% of the respective global totals, while China covers 6.5% of all dry lands. China's low biomass yields are indicative of a highly stressed ecosystem. China's high altitude dry interior of deserts and poor grasslands, overgrazing of the grasses at lower altitudes, conversion of forest to cropland and general low-quality forest coverage all contribute to the poor biomass productivity.

1. Biomass Production

The vast majority of China's biomass energy comes from biogas (71.9%), reaching over 700 million m^3 per year (651 Mtce). This is followed by crop stalks and straws at 231.8 Mt (14.1%, 127.5 Mtce), firewood at 181.6 Mt (11.6%, 105.3 Mtce), grasses and leaves at 48.0 Mt (1.9%, 17.3 Mtce) and 9.4 Mt of manure (0.5%, 4.5 Mtce) [EinC, p.21]. Most of the biogas production takes place in the south-central regions, where the agricultural byproducts are readily available and temperatures are warm enough to support the use of degassifiers. More than 4.5 million household agricultural degassifiers with capacities of 6 to 10 m^3 are in use, with 300,000 m^3 of large scale digesters and 300 biomass gassifier units operating in rural settings [CED t.II-32].

The reliance on stalks is a direct indication of China's poor forest quality. Total coverage is just 121.6 million hectares (ha), less than 12.7% of China's territory. China has repeatedly tried to implement afforestation plans since 1949, but of the 100 million ha planted, less than one third has survived. The Chinese include low growth density "shelter-belts" as part of their forest total, meaning that approximately 60% of China's so called forested areas are poorly stocked in secondary growth. Even if all of China's woodlands could be categorized as "closed" mature forests (more than 25% ground covered by canopy) this would still rank China no higher than 130th out of the world's 197 odd nations [Smil, p.21].

CHINESE FORESTED AREAS



China has very little full coverage forest, with most forested regions having little undergrowth and poor secondary coverage.

Source: *Energy in China's Modernization*, Vaclav Smil

[7] Phytomass includes all above- and underground parts of trees, shrubs, grasses, crops and aquatic plants.

What forest there is, as with the other natural resources, is not evenly distributed. The majority of the timber is in the southwestern provinces of Yunnan and Sichuan. Southwestern forest can annually sustain 25-30 tons of timber per ha, while those in the northwest can only supply 1-2 tons. Woody phytomass for combustion can be can be gathered from other forests (118 million ha at 600 kg per ha) for a total 71 million tons annually. Unfortunately, actual annual firewood consumption is more than double this rate, making natural forest biomass a very poor choice for China's future energy supply. Demand for new cropland, industrial timber and household fuel has caused a 55% deforestation in Yunnan and 30% in Sichuan.

2. Planned Biomass Production

Since biofuel consumption is associated with rural China, consumption is expected to drop as urbanization progresses. It will, however, be some time before sufficient alternative energy sources are available to the rural population to reduce consumption noticeably. In the interim biomass will remain the dominant rural energy source. Ministry concerns over deforrestation have driven efforts to reduce consumption volume by increasing consumption efficiency. When such efforts are combined with other fuel sources (coal, hydro, etc.,) some strain on the ecology may be reduced. New stove designs have improved efficiency by 40 - 60%, and new biofuel gassifiers are being made with efficiencies up to 70%.

Reforestation plans continue, but so far seem unable to keep pace with the rural consumption. The government encourages everyone to plant three to five fast growing trees each year to offset the losses in forested areas. Original predictions that claimed this plan would generate 85 Mt (49.3 Mtce) annually for consumption were overly optimistic and the plans have met with limited success [EinC, p.21].

Biomass was not included in the energy supply projection because it is not a commercial fuel source, and therefore has no impact on US energy security.

G. SOLAR RADIATION AND WIND

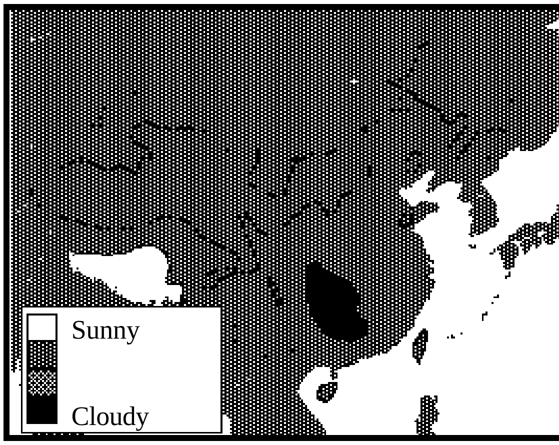
1. Solar Radiation

The first map of China's solar resources became available in 1978, confirming expectations. There is a general NW-SE gradient, with the most intense areas in the Xizang-Qinghai grasslands (eastern Tibet) and the minima in the southern interior. The distribution "makes for a nearly perfect mismatch between the total radiation received at the ground and population density" [Smil, p.10]. The lowest levels of solar radiation are found in China's most densely populated province of Sichuan. Sichuan has so much cloud cover that in its first decade of operation LANDSAT was only able to acquire two clear images of the region. [Smil, p.10].

Sichuan annually receives less solar radiation per year that the US Pacific Northwest or parts of northern Europe, while the whole Xizang-Qinghai plateau receives more than Arizona or New Mexico [Smil, p.10]. Xizang (Tibet) and other western provinces receive annual radiation between 1630 kWh/m^2 and 2320 kWh/m^2. Eastern provinces receive 930 kWh/m^2 to 1860 kWh/m^2, with the slightly better values of 1390-1860 kWh/m^2 in the northeast [EinC, p.24].

The overall contribution of solar radiation to power consumption has been negligible. Total solar array electrical generating capacity had reached only 1.8 MW in 1994 ['95CED, t.II-32]. Survey data indicates that only 200,000 m^2 of solar collectors are in use, mostly in the northeast, and there only for hot water supply in public service facilities [EinC p.25]. Even if the total solar collector area were 100 times larger, all these water heaters could only operate for five to eight months a year for a maximum nationwide fuel savings of 3 million tons of coal [Smil p.13].

CHINESE SOLAR DISTRIBUTION



China's regions of high solar generation potential are in the remote Himalayan Plateau and the western desert, while populated central China in perpetually cloud covered.

Source: *Energy in China's Modernization*, Vaclav Smil

2. Wind

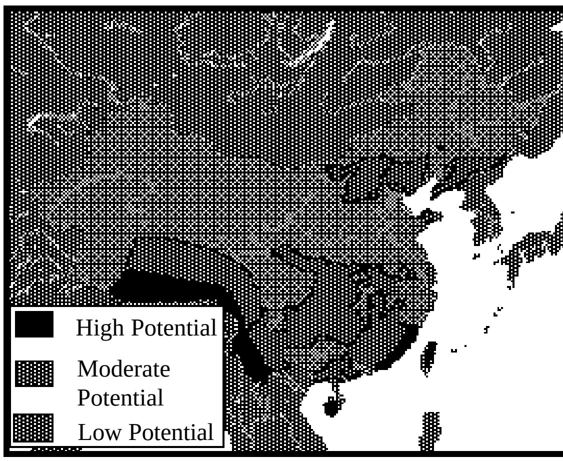
As with solar radiation, most of the windiest places are far from China's heavily populated central provinces. The mountainous areas in the northwest and the northern steppes are by far the windiest, closely followed by the central coastal areas. The densely populated interior, including the Sichuan basin and central Hunan, have calms for at least 30% of the year, up to 50-70% in some places. China's total wind generating capacity is estimated at 1,600 GW ($1.6x10^{12}$ W), with 100 GW in near surface flows. This is of the same order of magnitude as China's hydro potential, but very little of it will be tapped [Smil, p.14]. The greatest potential is in a huge 200,000 km^2 funnel created by the Altay, Kunlun and Tianshan ranges in northwestern Xinjiang. Again, this is a sparsely populated region making exploitation of local wind resources unlikely. The main focus of Chinese wind-power has been in the Nei Mongol grasslands (Inner Mongolia) where winds faster than 3 meters per second are present more than 200 days a year.

H. GEOTHERMAL

China is on the eastern end of the Eurasian tectonic plate, with a compaction region from the India plate to the southwest and a subduction zone with the Philippine plate to the east. With all this activity, it is not surprising that China has large geothermal resources. Most of the capacity is in southern Xizang (Tibet). The simplest indicator of geothermal potential is the distribution of hot springs. A nationwide inventory lists 2,412 separate sources. 279 have temperatures greater than 60ºC and 116 of those are in Xizang (354 total hydro-thermal areas in this province) [EinC, p.23].

The annual heat discharge of China's hot springs totals 111 PJ (3.8 Mtce), with 43% in Xizang, 26% in Yunnan and 4% from Guangdong. Mostly geothermal resources are used as a hot water source for greenhouses, aqua-culture pools and the textile industry. Nationwide geothermal resources suitable for electricity generation are much less than expected given the total heat output. There are a total of only 200 MW in identified resources and an additional 3500 MW in estimated reserves. Full exploitation of this resource would expand electricity generating capacity by less than 5%, and the location of the resources guarantees that few of these will be accessed in the next few decades [Smil, p.17].

CHINESE GEOTHERMAL REGIONS



The Chinese geothermal potential is due to tectonic activity between the East Asian Plate and the India and Philippine plates (Himalayas and southern coast).

Source: *Energy in China's Modernization*, Vaclav Smil

I. URANIUM / NUCLEAR

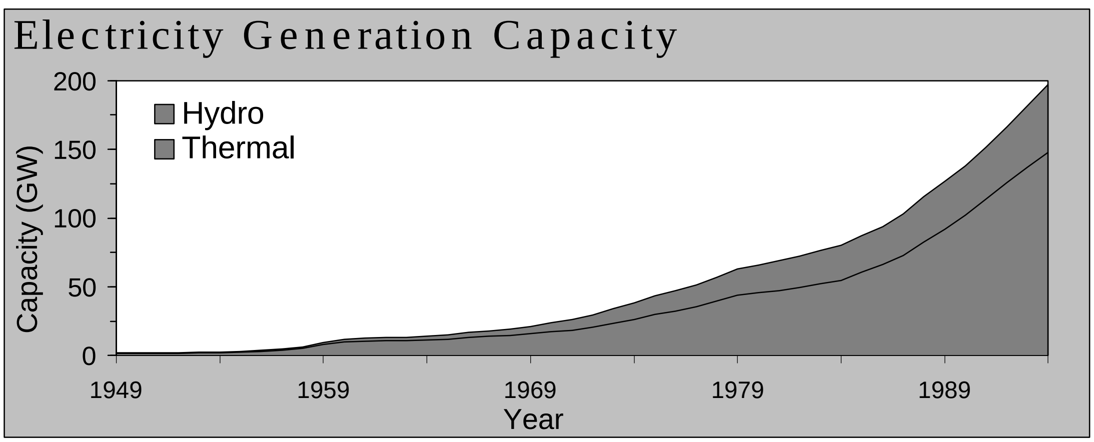
In 1990 China reported uranium resources equivalent to Australia's total reserves, which are the largest in the western world. The actual resource estimates are considered a State secret, while the released Chinese numbers seem to be exaggerated, again making evaluations difficult. If the Chinese category of "Speculative Resources" were to be included, their total would exceed an unlikely 3 million tons U [Owen, p.29]. China's reported uranium resources are concentrated in the northern provinces of Shanxi and Xinjiang, and in the south eastern coastal provinces of Yunnan, Guangxi and Guangdong. Uranium is distributed over 200 known deposits, mostly of the vein type associated with granites and volcanic rocks. Current estimations of recoverable uranium reserves have dropped 49% since 1993 to 51,000 tons U recoverable reserves [CED t.I-1, Puckett, p.9; Owen, p.29].

600 metric tons uranium were mined in 1993, down from 800 tons in ‘92, constituting 1.9% of the world total [‘93 UN, t37]. A mill dedicated to uranium exports is located at Hengyang, south of Chengsha, in Hunan province. The ore capacity of this mill is reported at 725,000 tons/year, yielding about 1000 tons U [Owen, p.29].

E L E C T R I C   P O W E R   P R O D U C T I O N

A. GENERATING CAPACITY

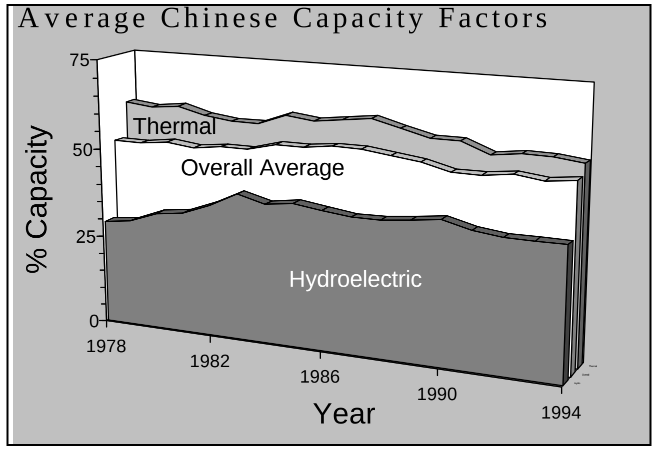
1. Overall



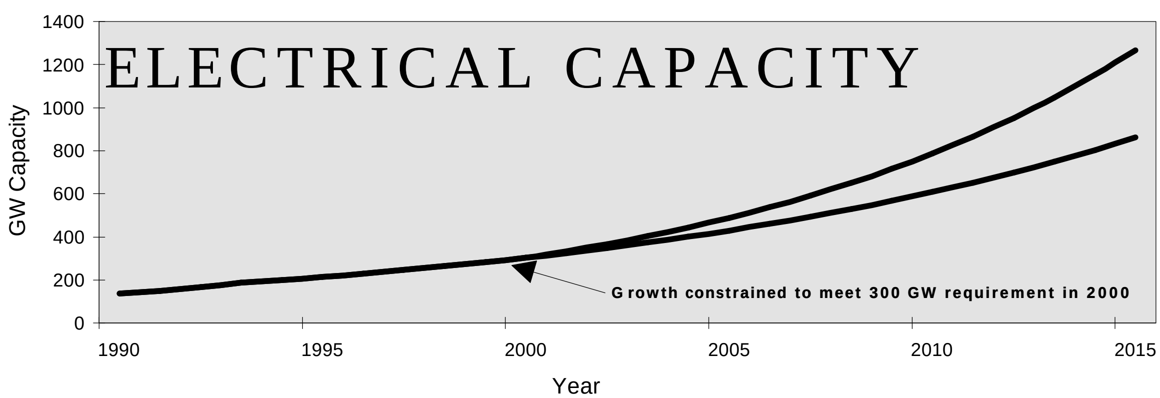
China intends to reach a 300 GW (3×10^{11} watts) generating capacity by the year 2000, adding 117 GW to the 1995 total at a cost of $100 billion. $20 billion is hoped for in assistance from foreign investors [IWPDC, p18]. In 1994 the State Planning Commission targeted 17 projects with a total generating capacity of 20 GW. In addition to the Three Gorges Project (13 GW) the commission intends to add ten hydro projects totaling 75 GW of new capacity, an additional thermally generated capacity of 9.2 GW, and 1.2 GW from the second phase of the Qinshan nuclear plant (totaling 175.2 GW) [IWPDC, p.18 & CMTIP]. If all of these projects are completed by the year 2000, the Chinese will have exceeded their stated goal by 58,200 MW. It must be noted however, that the ten hydro projects which contribute just under 43% of this increase are unlikely to be completed by the deadline as feasibility studies for the first two were not submitted until the end of ‘95 and large hydro- projects have a reputation in China for late completion.

Current generating capacity is 183 GW (1995) [IWPDC p.18], with 74% from thermal plants and the remaining 26% coming mostly from hydroelectric plants [‘92 UN ESY table

32]. Alternative power sources such as wind turbine generators, solar converters and geothermal plants produce so little energy as to be negligible.



China's electrical problems include frequent brown-outs and complete power failures. University students in northeastern China bring candles for reading light when going to the library. Rural homes stock up non-electrical light sources as a matter of course. Industries frequently purchase their own diesel generators as backups for the inevitable power outages. These problems are symptoms indicating that the increase in capacity has lagged demand. Capacity factors on major grids average 0.60 or higher, with the Eastern China Grid running at almost 0.70 (US capacity is 0.42). These are equivalent to load factors greater than 90% (90.8% load for 0.56 average capacity on Central China Grid, 1991) [CED, t.II-22]. Backup capacity is inadequate and as demand increases, especially in the developing free trade and industrial areas, electricity supply will need to increase dramatically.



Both the Standard and Maximum Supply scenarios for electrical generation capacity were scaled to meet the anticipated 300 GW capacity in the year 2000. This required a 7.2% annual growth rate. For the Standard scenario this growth rate was maintained, while for the maximum growth rate it was increased to 10%, representing an average of the best growth rates attained between 1985 and 1995.

2. Fossil Fuels for Electricity Generation

Thermal plants produced 75.6% of China's total electricity, and consumed upwards of 243 Mtce of fossil fuels in 1995 ['92 UN ESY t.32 & OSD p.II-27]. Of this consumption 86.6% was coal, 11.5% was petroleum and 0.7% came from natural gas (1989) [OSD p.II-27]. Thermal generation accounts for an increasing portion of total electricity generation. The growth rate of total generation from 1990 to 1993 was 9.3%, while the growth rate for thermal generation was 10.2% [CED, t.II-17].

Chinese thermal plants tend to be small, with only 15 having capacities greater than 1 GW and with the majority being less than 100 MW [OSD p.II-27]. Inefficient low and medium pressure turbines compose about 20% of the thermal capacity, putting the conversion efficiency at 27%. The Chinese consumption fraction measured 0.431 kgce/kWh, 14% more inefficient than the US figure. If pollution controls were to be installed on these plants efficiency would drop even further.

Most of China's thermal capacity is near the load centers in the northeast and eastern coastal areas. Many newer plants have been built at coal mine mouths to reduce the volume of coal needing rail transport. China has built no oil burning thermal plants in the past decade, saving petroleum for other domestic uses and export.

3. Hydroelectric Generation

Installed hydroelectric capacity had reached 50 GW in 1994, representing 18% of the total electricity generation and 13% of the recoverable hydro reserves. Hydroelectric capacity has grown steadily, averaging 7.73% per annum since 1986.

There are more than 150,000 small hydro plants in rural China. Two thirds have generating capacities less than 500 kW, and the remainder have capacities between 500 and 12,000 kW [EinC p.20]. At the end of 1994 a little over 48,000 of these with a total installed capacity of 15,050 MW had been interconnected, forming 40 local inter-county power grids in rural China.

It is likely that hydroelectric power will continue to be the generating source of choice in many southern rural areas where coal reserves are minimal. However, even if the large scale projects like the Three Gorges Project[8] (TGP) are completed and operate at capacity, hydroelectric generation will be able to supply only 18% of the anticipated power demand.

4. Nuclear Generation

China has two nuclear power plants on line with a 2.1 GW total capacity. The first is a domestically designed 300 MW pressurized water reactor (PWR) near Shanghai, which is currently receiving a two reactor upgrade from South Korean firms. The only other

[8] The Three gorges Project is a large Hydro-electric power generating station under construction on the Yangtze River in central China. It will house twenty six 500 MW turbines and include three deep-water locks for to allow the development of inland waterway shipping capacity.

operating plant is another PWR with two 900 MW French built reactors which supply power to Hong Kong from Daya Bay, both went on line in the spring of 1994.

Nuclear power is very appealing to the Chinese government in that it offers power independent of coal. The Chinese seem willing to accept the limitations of an open fuel cycle and decommissioning problems for the environmental benefits of no ash and sulfur emissions. On a cost basis nuclear plants are appealing for their reduced infrastructure costs, while expanded nuclear fuel use would free up rail-freight capacity and increase the amount of coal available for export. The all Chinese Quinshan plant consumes only 10 metric tons of fuel annually, and the Daya Bay plant 30 metric tons. Coal burning plants of the same capacity would consume more than 1 and 3 million metric tons respectively of standard coal. This is the equivalent of two versus tens of thousands of railway car loads. Also, a thermal plant requires specialized railroads, piers and other transport facilities representing a huge investment in support infrastructure.

China will add 6,600 MW to current capacity by 2004 through upgrades of the two existing plants and construction of two additional plants. The first new plant will a PWR in northeastern China's Liaoning Province, and the second an additional Daya Bay plant to supply power not to Hong Kong this time, but to Guangdong province and China proper. The new plants will be built with foreign reactor parts. The second Daya Bay plant will have two 985 MW PWRs built by Framatome, while the Liaoning station will use two 1,000 MW Russian reactors. The new plants are expected to go on line in 2003 and 2004 respectively. The upgrades of the two on line plants will also use western suppliers. The Quinshan plant, which had contracted with a South Korean firm for the new reactor vessels (a deal which fell through after China was unable to obtain suitable financing), will now obtain parts from Framatome (steam supply and fuel assembly components) and Westinghouse (turbine generators and possibly the reactor vessels) for major components.

There is talk by China of increasing its nuclear capacity by nearly 2000% to 40-50 GW by 2020, but there is some doubt as to China's ability to supply fuel for such a large number of conventional reactors. If the 40 GW goal is reached it is likely that the Chinese would require a foreign uranium supply, but experts suspect that this goal is unreasonable. More than ten provinces are conducting feasibility studies for nuclear plant construction, but it is unlikely that all will be approved. China lacks the necessary investment funds, and the initial lump-sum required to start a nuclear plant is much more than that for a thermal plant, even with the reduced support infrastructure costs. Additionally, the World Bank considers nuclear plants too dangerous for developing nations and does not provide financing for nuclear projects.

4-a. Nuclear Waste and Fuel Reprocessing

As of 1991, all nuclear waste was stored in temporary drums. Construction of permanent waste dumps in eastern and northwestern China is still underway. The eastern dump is intended to receive the waste from the Qinshan and Daya Bay plants, while the northwestern facility will handle waste from China's nuclear weapons testing area.

China has yet to build a commercial fuel reprocessing plant, but plans have been submitted for the construction of a Purex [9] plant in western Xinjiang Province. The plan calls for spent fuel to be transported to the reprocessing plant after 3 to 5 years storage in reactor site pools. Once the uranium and plutonium have been recovered, waste will be sealed in cement for underground burial. The proposed Purex reprocessor would be able to handle more than 30,000 kg of PWR spent fuel annually.

5. Alternate Sour ce Generation

China has experimented with electricity generation from alternate sources on a small scale. Total generating capacity from these sources is less than 25 MW, but they may be relevant for future planning. It seems unrealistic that any non-conventional source will become a primary power supplier, even on a local basis, but their potential as backup to relieve grid capacity overload should not be overlooked.

China has seven geothermal electrical power generation stations. Six have capacities below 1 kW, and four of these are inefficient binary installations which use hot water (67ºC-91ºC) to vaporize a working medium (butane or chloroethane) with a lower boiling point. The Yangbajang station is the only medium sized wet-steam plant in operation with three 3 MW units and one 1 MW unit on line. Unfortunately the inefficiency of these turbines limits production capacity, and the 1983 geothermal capacity of 8.4 MW has not been improved upon, although Ministry figures for the theoretical potential range as high as 25 MW. In either case, this is two orders of magnitude below US capability, representing less that half a percent of the worldwide geothermal electrical power production.

In 1990 China had a total of 122,000 wind turbine generators (WTGs) installed, bringing the wind generated capacity to 12.91 MW. China's first wind farm of three turbines was commissioned in 1986 on the eastern sea-coast of Shandong province. By the end of 1993, this farm had grown into 92 grid connected WTGs with a total installed capacity of 11,631 kW. At Nan'ao Island in Guangdong, a 1.68 MW wind farm generated 25% of the district's 16.8 million kWh [Yongfen, Pengfei]. This would indicate that wind resources can and should be utilized where possible to support local power grids.

[9] The Purex system is a fuel reprocessing technique which separates plutonium and uranium from reactor fission products.

A. INVESTMENT, CONSTRUCTION COSTS & INFRASTRUCTURE

Detailing Chinese investment is difficult. There are differences between reported and actual investment, inconsistencies in coverage and changes in the definition of "investment". However, where the Chinese spend their money is still the most significant indicator of Chinese energy policy priorities.

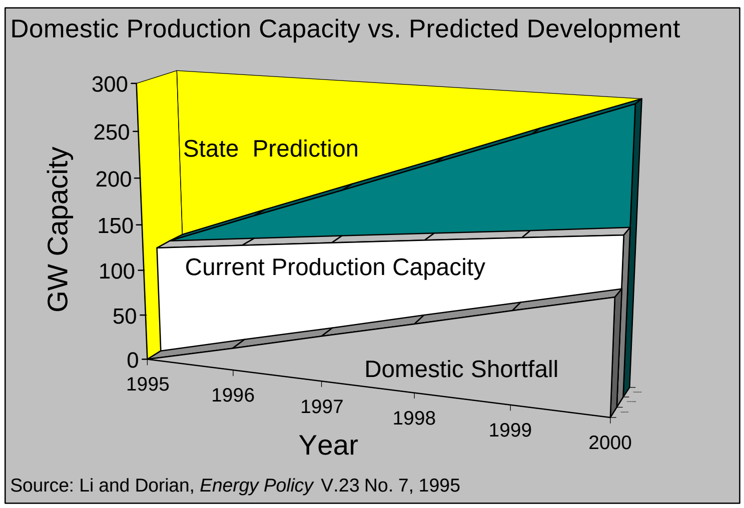
The Chinese government has spent an ever increasing portion of its available capital on energy related projects. Energy related capital investment has been growing an average of 3.9% annually between 1980 and 1990. In 1993 the State spent a total of ¥765.8 billion, 60% on capital construction, 20% on energy industry investments and the remaining 20% on other projects [CED, t.III-1]. Figures for 1995 place total investment in fixed assets at ¥1.7 trillion, with 53% going to infrastructure. Of the ¥84.67 billion spent on energy industry investments, 66%, or ¥55.83 billion went towards capital construction (power plants, sub-stations, grids, etc.,) while 15% or ¥12.51 billion went towards technical upgrades (replacing old equipment) [CED II-16, II-18, III-1].

With the 1995 total generating capacity at 183 GW, extrapolation of past trends using energy investment in capital construction and the annual increase in total energy capacity indicates that to reach the stated goal of 300 GW total capacity by the year 2000 would require ¥611 billion ($72 bn.), or ¥122 billion ($14.4) annually for the next five years. This agrees closely with Chinese estimates as quoted by CS First Boston Bank at $14-15 billion. These figures do not include the costs of replacing antiquated equipment such as generators, transmission lines and sub-stations. The Chinese estimate total costs including upgrades and maintenance to reach $100 billion [IWPDC, p.18].

1. Turbine Manufacturing Capability

Most Chinese turbines have capacities less than 100 MW, but the Chinese turbine industry is capable of manufacturing turbines with capacities up to 300 MW. There are fewer than a dozen 600 MW systems in operation, and these are almost entirely imported. Of the additional fifty high capacity turbines being installed in the next seven to eight years almost all will be imports. The Chinese do have a few domestically built 600 MW turbines in trial operation but it will be several years before they are capable of manufacturing these in any relevant quantity. To accelerate their domestic power system manufacturing capabilities the Chinese have engaged in joint ventures with ABB, GEC Alsthom, Mitsubishi, Hitachi, Toshiba, Westinghouse and GE. Additionally, in the past two years the Chinese have entered into joint ventures with Japanese and US companies to acquire technology for the manufacture of 900 MW units. As the Chinese gain expertise and familiarity with the technology, a greater portion of the installed large capacity systems will be manufactured domestically.

As stated previously, China intends to bring its 1994 199 GW generating capacity up to 300 GW by the year 2000. This will be done by not just by adding new capacity, but also from increases in efficiency, though refits and upgrading old technology. Unfortunately for China, the domestic turbine manufacturers, operated by the Ministry of Machinery Industry (MMI), are unable to accomplish this unaided. MMI's current production capacity is only 9 GW per year. Even if all other potential turbine manufacturers in China are included annual production only reaches 12 GW [Stinton]. This is considerably short of the necessary 17 GW per year in new capacity, and even shorter of the total 36.6 GW per year including upgrades and refits. Even an optimistic appraisal of Chinese production will be 29 GW short in new capacity, and since at least some refits will be required China may fall as far as 147 GW short of the 300 GW goal. Without purchasing foreign equipment, China is unable to meet the demands for electricity, and would severely inhibit growth in its electricity hungry new high tech industries. China would fall so far behind that it would take ten years to make up the difference.



However, in recent years China has bought up to 20% of its generating capacity from foreign suppliers. To effect a full refit and fill the 36.6 GW maximum annual requirement, the Chinese would have to purchase 24 GW of foreign equipment annually at a cost of $19 billion. This is not likely to happen. A more estimate would be the purchase of 5 GW to 10 GW in foreign equipment. Which in turn implies annual costs of $4 to $8 billion [10], or a total of $24 to $48 billion before the year 2000.

2. Power Investment Costs

Many foreign analysts are quoting the Chinese new electricity generation capacity as costing $1,000 per installed kW. Calculations from installed capacity and investment in energy industry capital construction yield a lower figure of $610 per kW, which agrees

[10] Assumes a cost of $800 per kW for foreign suppplied equipment

with Ministry of Electric Power Industry (MOEP) and other DOE study results[11] of $600 - $720 per kW for thermal plant generation [Stinton].

Prices for alternate sources of energy are slightly more expensive. MOEP estimates place hydropower generation at ¥ 7,000/kW ($840/kW) including heat generation and distribution for large scale projects and ¥ 12,000 ($1,450/kW) for those on a smaller scale. Wind turbine generation, including associated costs, is placed at ¥ 10,000/kWe ($1,200/kW). The limited extent of China's current nuclear capacity has made nuclear the most expensive, with current costs of $2,000/kW. Industry experts believe that with expansion of the program costs will drop below the typical value of $1,700/kW to $1,200/kW by 2020 [Stinton].

3. Power Plant Operations, Upgrade and Maintenance Costs

China's low labor, fuel and equipment costs give it a comparably low operational rate. Many nuclear power advocates claim that nuclear power is competitive with coal-fired plants (¥ 10,210/kW for nuclear vs. ¥ 8,331/kW for coal) but studies indicate that while initial construction costs may be similar in China for thermal and nuclear plants, the operational and maintenance costs for nuclear plants will be at least 21% higher [Zongxin, pp. 780-2, 1995]. In the US, nuclear plants are slightly more expensive to build but less expensive to maintain than their fossil fuel equivalents.

Additional costs will be incurred as plants upgrade their environmental controls. Most fossil fuel fired plants utilize in-stack particulate filters, and many of the larger new plants also have electrostatic precipitators (require frequent maintenance but otherwise work very well and with high efficiency). Recently enacted air quality legislation makes "it more likely that new plants will at least include space for future installation of" flue gas desulfurization (FGD) equipment [Stinton]. Multilateral agency funded projects now require FGD installation, and a very few Chinese plants already have them installed.

4. Power Plant Financing & "Doing Business in China"

China needs foreign investments to finance its electrical power development, but so far has been unable to negotiate more than a few large projects. In fact recent trade policies have made foreign companies working in all markets rethink doing business with China. Uncomfortable with the thought of loosing market share and profits to "outsiders", China is using coercive tactics to make foreign companies pay for access to it's fast growing markets with technology transfer. The telecommunications Minister criticized Motorola saying the company had "earned quite a lot of money in the mobile telephone market in China. It's high time for them to transfer some technology" [WSJ, Dec.19, '95 p.A12]. Under such pressure from the Chinese, and fear of losing out to competitors like the French conglomerate Alcatel, Motorola agreed to build a $720 million semiconductor plant with full technology transfer [WSJ, Jan. 15, '96, p.A9]. The Chinese are very

[11] *A Review of Power Plant Costs in China*, Jonathan E. Stinton ,LBNL Energy Analysis Program, draft copy, December 1995

interested in such ventures not only because they eventually hope to export the high-tech products but because the central government still controls segments of the economy which in other countries are purely private. Many state run enterprises have been forced to shut down production lines as a result of the measures taken by the government to curb inflation [WSJ, Jan. 2 '96]. With state enterprises failing as foreign companies take increasing portions of the market share, Beijing is insisting on technology transfer as a means to keep its own industries alive.

As a result, most foreign companies conducted investment at the local level on low cost projects (less than $30 million or ¥ 255 million) which do not require central government approval. However, lately even this sort of investment has cooled with the spread of rumors of unofficial caps on rates of return.

In seeking loans for power and industry development, China amassed $100 billion in debt as of 1994. In the past 15 years China has used $14.5 billion in foreign funds to complete 64 power projects totaling 10.7 GW, with more than an additional $1 billion committed to projects for 1995 [IPWDC, p.18; Stinton p.3]. The largest contributors were the World and Asian Development Banks, who earmarked most of the monies for hydroelectric projects. These numbers are insignificant when compared to the cost of meeting the 300 GW goal. China's domestic manufacturing will see minimum shortfall of 43 GW in new capacity, and up to 123 GW in overall deficit [12]. Using a modest $700/kW for imported generation capacity, China will require $30 billion to $86 billion (¥ 255 to ¥ 732 bn.) in foreign supplied electrical power generation equipment[13].

Large companies have been trying to establish joint venture or direct stake agreements but have been unable to persuade the Chinese. In 1994 Goldman Sachs went so far as to pull out of a major funding deal for power plants in Shandong province when Beijing imposed a 12% ceiling as the return on equity. At the same time Beijing passed a rule preventing foreign investors from holding a majority stake in large power plants or equipment manufacturing ventures. A spokesman for Siemens recently commented that "conflicting information [from Chinese sources] and changing regulations have hampered investments in Chinese [energy] projects" [IWPDC p.19].

5. Infrastructure Construction

For the purposes of this report energy sector infrastructure consists of the physical apparatus required to transport and distribute resources for both consumption and trade, as well as the mechanisms for power distribution such as electricity grids, sub-stations and transmission lines. Information on total infrastructure costs and investments is difficult to obtain as the Chinese do not organize their data in this fashion. However, trends can be observed and estimates based on cost of existing infrastructure and planned expansion can be made.

[12] See: Cost Finance & Trade, A.1. Turbine Manufacturing Capability

[13] This cost depends on whether China engages in no refits ($30 bn.) or in complete refits ($86 bn.). Refits might be delayed to stretch cost schedule out.

China’s 1994 investments in fixed assets increased a dramatic 28% to a total of ¥ 1.59 trillion ($274 bn). Most of this investment went into construction of freight transportation resources such as railways and port facilities and into electrical power distribution systems. Total freight volume increased 5.8% to 11.8 billion tons. The volume of rail freight was 1.25 trillion tons/km, and the volume handled by major coastal ports was 730 million tons.

5-a. Power-lines

Of the $5.5 billion invested in Chinese power industry capital construction in 1990, $808 million was spent on power distribution. Although in straight numbers this was an all time high, it represented a share of only 14.7%, down from an average of 21% in the preceding five years [CED III-5a].

5-b. Railroads

With coal fired plants comprising the majority of China’s electrical production capacity, the ability to transport coal from the mines to the generation centers becomes a major concern. The 653.2 Mt of coal shipped annually accounts for 42% of China’s total rail freight transportation capacity, and 50-70% of all rail traffic from Beijing to Guangdong, Shenyang, and Shanghai [‘95 CED t.II-30]. In the past, lack of rail capacity forced mines to abandon coal at the pit mouths while industries which required coal had to cut back on production for a lack of it. Railway lines are vital to the economic growth of remote areas like western Xinjiang, and again a lack of transport capacity has slowed the development of the region, exploitation of its natural resources and transportation of those resources to the consumption centers in the east.

Consequently China is adding to its rail capacity at a furious rate. China laid a national record 3,346 km of railways in 1995 at a cost of ¥ 33.2 billion[14] ($3.9 bn. total, at ¥ 9.7 million/ km)[15]. 1994 freight handling capacity reached 1.57 billion tons, 11 million tons more than scheduled, with an additional 1.89 billion passengers carried. Ten key rail construction projects are either underway or recently completed, including the 2,538 km Beijing-Kowloon line which opened in February of 1996, and a 1,622 km double track from Lanzhou to Xinjiang (opened September ‘95) as well as a number of other single and double lines under 1,000 km. In total, some 6,000 km of new railway line and 3,500 km of double track lines were completed between 1990 and 1995, with 2,600 km electrified.

Chinese rail freight capacity is overloaded. Twenty million tons of coal is forced into stockpiles annually for lack of transport. A few mines have stockpiles of over 80 Mtons waiting to be shipped. Lately, new power plants have been constructed literally at coal mines to reduce the need for long distance freight capacity. However demand at remote sites has still caused an increase in average freight distances to over 400 km from the 1990

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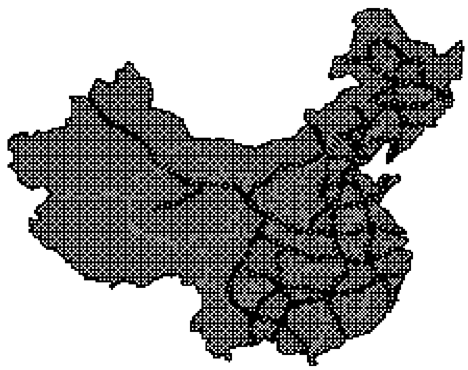
[14] 1994 Yuan (¥)
[15] In 1996 currency: ¥9.7 million/km = $1.1 million/km; or 103 km/ billion ¥ = 874 km/billion US$

average of 270 km [*Energy Policy* 22(7), p.613]. In 1994 railways handled 659 Mtons of coal, 42% of China's total freight capacity.

It is unlikely that the 1994 railway development rate can be maintained since a significant fraction of that came from doubling single track lines and improving existing track. However, the Chinese have demonstrated that they are capable of generating 3,000 - 4,000 km of new track annually at a cost of ¥ 29-39 billion ($3.4-4.6 bn.). In remote areas the cost per kilometer may increase by as much as 21%[16].

CHINESE RAIL SYSTEMS



China's rail system is under developed. North to south freight traffic is saturated, forcing coal users in southern China to use low grade local coal, instead of the high grade coal from northern mines. Also, minimal rail capacity in the western desert is hampering the development of oil extraction in that region.

In the State plan for 1996-2000 China allocates ¥ 330 billion ($39 bn.) for railways, including ¥ 250 billion ($24 bn.) for track construction and ¥ 80 billion ($960 million) for engines and trains. 10,000 km of new track is scheduled to be lain by the turn of the century.

5-c. Sea-Ports and Shipping Capacity

Increased development in industry, a growing GNP and demand for the transportation of resources has caused a surge in port shipping volumes. The Bohai Sea's shipping industry has seen tremendous growth in the past decade, with more to come. It is the main shipping region, especially for export and transport of coal by sea to south-eastern China. The major industrial and production areas of land-locked Shanxi, Beijing, Inner Mongolia and the northeastern province of Liaoning all ship through the Bohai Sea. The local economy accounts for one third of China's freight transport, one fourth of postal communications and more than half of all coastal shipping to foreign customers [*China Today*, Feb. '95 pp.43-44]. The area is also China's largest transit base for grain, crude oil and coal. In fact coal makes up 20% of all freight moved by water [EinC p.17].

Planned construction includes a special coal quay at Qinhuangdao Harbor with three deep water berths and a 30 Mton capacity, 6 more berths at Dayaowan Harbor for an additional 3.1 Mtons capacity, five deep water berths at Dailan Harbor with 2 Mtons capacity, an

[16] Estimated price increase calculated from difference in figures for 1994 total rail construction and cost (converted to '96 ¥) and track length versus cost for the new Beijing-Kowloon line.

extension of Dandong Port for an additional 950 thousand tons, six berths at Yantai (Shandong province) for 3.4 Mtons, six sundry goods berths in a new wharf in Qinghangdao for 3 Mtons, 2.1 Mtons in sundry goods berths at Lianyungang Harbor and an additional 25 thousand tons of coal capacity at Shanghai. This totals 44.6 Mtons of increased capacity by the year 2000 [TCMTIP-PRC'93-'00].

5-d. Coal Extraction

The costs of the projected capacity increase to 1400 Mtons annual coal production by 2000, including transportation and infrastructure improvements are ¥621 per annual ton ($73). The projected 295 Mtons per year increase in capacity from Ministry mines will require ¥21.4 billion per year. Investment in coal extraction and processing in 1989 totaled ¥27.6 billion (1995 ¥, excluding privately owned mines) so financially this goal is certainly achievable [CED III-4; OSD pII-21].

5-e. Oil Pipelines

Most oil is transported by pipeline. Where pipelines are unavailable, railway lines substitute. There is a total of 10,000 km of oil bearing pipelines from drilling fields to refineries. To alleviate strain on the rail system a 1,000 km pipeline from the Tarim basin in Xinjiang to the refineries in Sichuan is currently under construction is at a cost of ¥5 billion. Since it is unlikely that the oil-fields in the northeast will see much increase in production, it is reasonable to assume that in the near future most new pipeline construction will be onshore from western Xinjiang to central China. Using the Sichuan-Tarim pipeline as a guideline, we may reasonably assume a cost of ¥5 million/km. As the western region becomes more developed the expense will decrease, but that development will be slow. If China pursues off-shore drilling, pipelines from these sources are expected to be considerably more expensive.

B. IMPORTS & EXPORTS

In the context of total world energy trade, China's current exports are of little significance. In 1993 China imported only 35.6 Mtce in energy resources while exporting 53.0 Mtce. Most of the export volume was oil, 19.4 Mtons (27.8 Mtce), and hard coal, 18 Mtons.

439 Mtons of coal were traded internationally in 1993 [17] ['93 UN, t6]. China accounted for only 4% of the trade volume while contributing 33% to global production ['93 UN, t6]. If domestic consumption of coal can be reduced, China has the potential to become a major coal exporter. Currently, the high ash content and lack of washing facilities make Chinese coal less attractive than its competition.

[17] World import total, exports not included to avoid double counting coal volume; 1993 UN Energy Statistics Yearbook: Table 6

Japan was the largest single buyer of Chinese coal in 1993, purchasing 6.2 Mtons, but in 1992 Japan bought no Chinese coal at all (substituting with supply from the Russian Federation). This is perhaps due to the Japanese industrial need for high grade washed coal. Upwards of 55% of the Japanese imports are low ash and sulfur content washed coal from Australia, with Canada and the United States as the next largest contributors [‘93 UN, t7]. The lack of coal washing facilities has prevented China from contributing more than 10% to the Japanese imports. If the Chinese wish to expand their role in the world coal market, they will need to upgrade their washing capacity.

There is some concern over China’s ability to consistently deliver coal for export. Domestic consumption is so high and freight handling systems are so overloaded that a physical inability to deliver in large volumes is considered likely. The recent improvements in rail capacity on east-west lines from Shanxi to ports on the Bohai Sea and seaport freight capacity improvements may reduce bottlenecks but an ability to export on a large scale has not yet been tested.

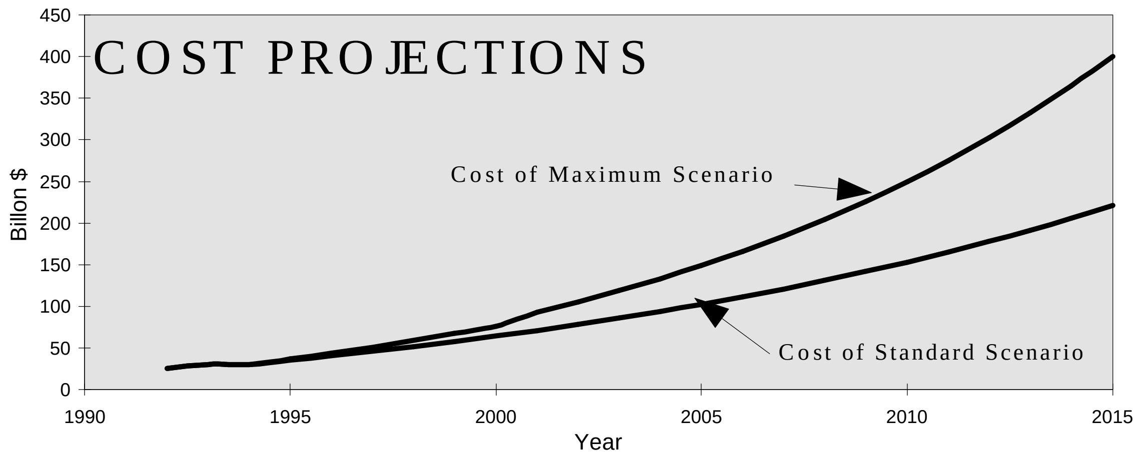
China’s oil trade is one area of immediate concern. In 1994 China produced 147.7 Mtons of crude, while consuming 153.3 Mtons. China imported 13 Mtons and exported 7.4 Mtons. Of the imported crude, 39% came from Indonesia, with the next largest reported fractions at 3% from Libya, 2% from the United Arab Emirates, and with Saudi Arabia and Iran contributing 1.6% and 1% respectively [‘93 UN t15]. Some analysts are concerned that with automobile ownership on the rise, China may soon become a major buyer of mid-eastern oil, causing prices to climb and creating the potential for conflicts with US energy interests. However, although the anticipated oil imports will be large for China, they will be small compared to the expected consumption increases in the US and Europe. The effect on world energy markets will be minimal. In the past, China has exported quantities of its own heavy crude to help fund domestic projects and it is likely that should Chinese oil production increase this trend will continue.

China’s 1993 uranium production fell 25% from 800 to 600 metric tons [’93 UN t37]. Since 1985, when domestic uranium first became available for export, China has sold it. The first shipment of 50 tons went to West Germany in 1985. As of 1990 China was the main supplier for most of that country’s annual 400 tons U demand. To place that in perspective, 1993 statistics put China’s uranium sales at less than 1.5% of the global total. Additionally, rumors of clandestine uranium sales have been reported in the western press. China is suspected of having sold enriched uranium to several countries developing nuclear weapons programs such as Iraq, Pakistan and South Africa as well as having sold heavy water (necessary for reactors using natural uranium) to Argentina and India. However, even if true, while these sales may have tremendous political significance they do not affect trade or US energy security. With its limited mining facilities, 725,000 tons/year mill capacity and plans for up to ten additional domestic nuclear reactors China is unable to trade nuclear fuel products on any great scale.

C. TOTAL COSTS TO SUPPLY ENERGY RESOURCES & ELECTRICITY

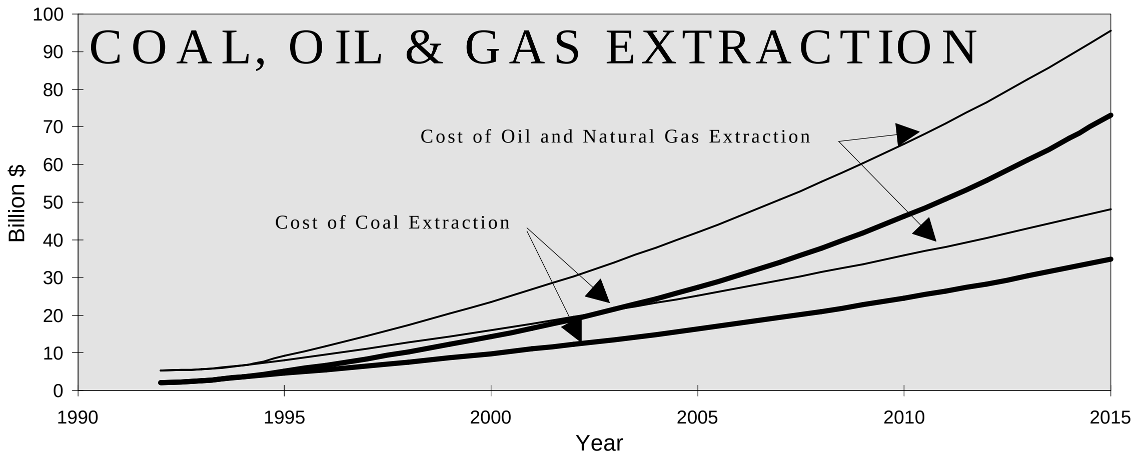
Both the stated energy goals and our predictions for resource supply are within China's financial grasp. In 1995, the total expenses for energy resource extraction, installing new electrical generating capacity and actual electricity generation were approximately $36 billion, or 5.6% of the $643 billion Chinese GDP.

To reach the 300 GW total generating capacity by the year 2000, China will spend at least $12 billion on new electrical generation capacity, with an additional $60 billion spent on energy infrastructure and $100 billion spent on refits and upgrades[18]. These figures imply a total expenditure of $172 billion, or $34.4 billion (¥ 292 billion) spent annually for the next five years on electricity. In 1995 $12.5 billion was spent on electricity generation, with an additional $10 billion spent on new capacity and refits. This means that the Chinese need to spend ever increasing amounts to meet their goals and sustain past growth rates.

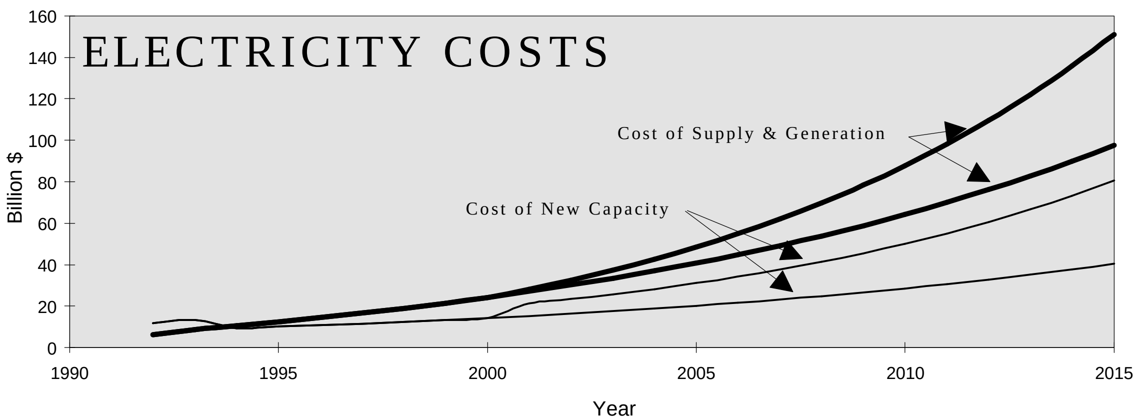


By the year 2000, coal extraction will cost between $10 and $14 billion depending on the production rate (*Standard* or *Maximum Supply Scenario*). Actual electricity generation will cost $24 billion, with an additional $14 billion spent on increased generation capacity. Meanwhile oil and natural gas extraction will cost between $16 and $23 billion, for total costs in the year 2000 of $64 to $75 billion (double the 1995 expenditure), again depending on production rates.

[18] See preceding sections 'Turbine Manufacture" and "Power Investment Costs" for more details.



By 2015 these costs will have again increased significantly, with $35 to $73 billion spent on coal extraction, and $48 to $96 billion spent on oil and natural gas extraction. Electricity will cost between $98 and $151 billion for generation and supply, with an additional $41 to $81 billion spent on new capacity; for totals of $222 to $401 billion[19].



As large as the projected expenses become in 2000 and 2015, they still represent similar fractions of the anticipated GDP. Expenses for extraction, electricity generation and newly installed electrical generation capacity will increase from the 1995 value of 5.6%, to between 6.1% and 6.9% of a $1.1 trillion GDP in 2000, and between 6.4% and 11% of the anticipated $3.47 trillion GDP in 2015. Since the Chinese have been willing and able to devote similar fractions of their GDP to exactly this type of investment in the past, it is reasonable to assume that they will continue to do so in the future.

Since it is unlikely that the Chinese will spend 11% of their GDP in this fashion, this data indicates that the "Standard" scenario with a 6.4% GDP fraction in the year 2015 is much more likely to represent actual energy resource development in China than the "Maximum" scenario.

[19] Figures do not include associated costs such as resource transport, nor do they include the costs of associated infrastructure such as rail lines, new highways, power transmission lines or the like.

ENERGY CONSUMPTION

CHINA'S FAST GROWING ECONOMY WILL CAUSE ENERGY CONSUMPTION TO INCREASE EXPONENTIALLY

A. INTRODUCTION

Recent Chinese energy history suggests four trends affecting demand for energy fuels: (1) rapidly growing commercial energy consumption spurred by the rapid pace of economic growth, industrialization, and improving living standards; (2) fuel substitution in industry and home use; (3) inability of energy fuel suppliers to keep pace with rising consumption; and (4) improved efficiency of energy fuel utilization, particularly in the industrial sector.

While China's energy consumption per capita is currently only one-sixth that of OECD countries, China's population growth and overall demography ensures significant continued pressure on energy demand. Currently eighty percent of residential energy consumption is provided by non-commercial biomass, mainly cropstalks and fuelwood. However, the expected increase in population from 1.2 to 1.6 billion people by 2030, a rural-to-urban migration with concomitant shift from non-commercial to commercial energy fuels, and improvement of living standards moving the entire population closer to the OECD norm of per capita energy consumption will severely impact energy demand.

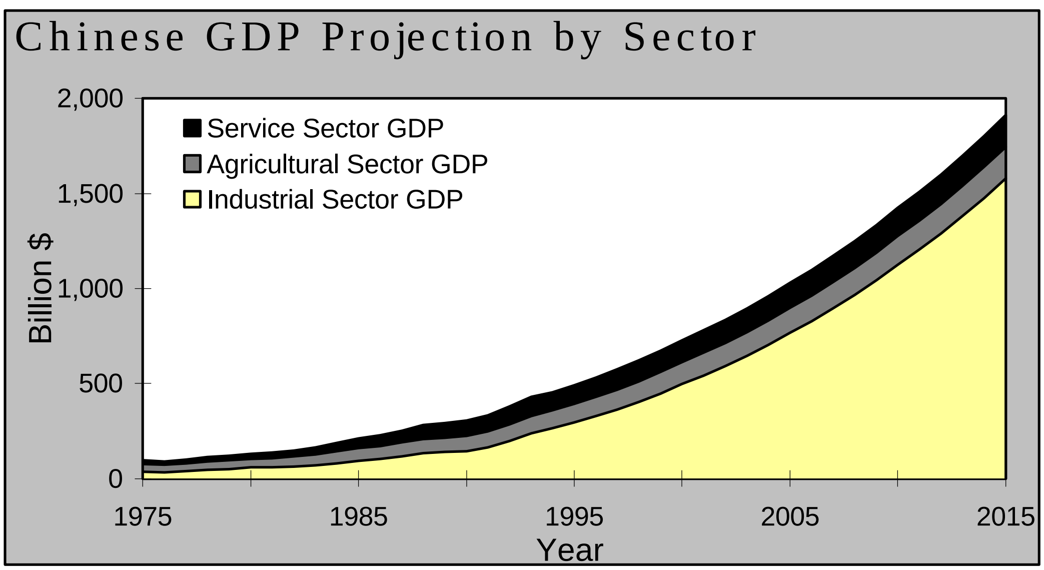


Figure 1

Source for historical data: The World Bank

Already, increases in the standard of living and have resulted in an influx of home appliances, accompanied by an increase in demand for new energy fuels such as electricity and natural gas as substitutes for coal. Meanwhile, rail traffic is saturated, resulting in more heavily traveled roads for both freight and personal transportation, significantly increasing traffic and motor fuels consumption. This demand for oil and gas from the residential and transportation sectors has caused China to switch from a position of net exporter to net importer of these fuels within the last four years; while demand for electricity is so high that China operates electric power grids with standard load factors far above US operational norms.

Growth of energy consumption has been so rapid that in the fifteen years before 1994, total final energy consumption in China more than doubled to 640 million tons of oil equivalent (Mtoe), and it is expected to redouble by 2006. As China's most abundant and accessible energy source, coal made up 75% of the 1994 consumption (including coal used in electric power generation), with oil constituting 17.4 %, natural gas 1.9%, and hydroelectric power the remaining 5.7% (Figure 3). That same year (1994), industry accounted for 61% of the energy consumption by sector, while transportation held a 10 % and the residential/ commercial building sector held a 20% share. This composition has been relatively constant over the past ten years (Figure 2).

The aggregate efficiency of Chinese energy consumption has improved in recent years. However, energy consumption per dollar of gross domestic product (GDP) remains more than ten times higher than OECD countries. Thus, China has an opportunity to relieve some pressure on energy fuels demand by further increasing the efficiency with which energy is used. Studies show that 80% of the reduction in energy intensity, defined as the value of total energy consumption per unit of GDP (*see Methodology section*) between 1980 and 1985 was due to industry. Of this 80%, 91% is due to real efficiency improvement, and only 9% to structural changes (Levine, et al. 1992). China could do more. Although the government has promoted energy conservation and accelerated the supply of energy through the use of market mechanisms, energy use is still inefficient due to 1) high dependency on coal[1], 2) inefficient industry[2], and 3) incomplete price liberalization[3] (Ishiguro, et al. 1995).

B. METHODOLOGY

Chinese final energy requirements[4] are projected by sector and fuel type to the year 2015 using

[1] The average thermal efficiency of the coal boilers used in the industrial sector is estimated at 50 to 60%, while the efficiency of the oil and gas boilers used in industrialized countries is 80 to 90%. The thermal efficiency of coal stoves used in the household sector is estimated at only 20 to 25%. That of modern gas stoves is in the range of 55 to 60%.

[2] The industrial sector has been growing rapidly, and its share of final energy consumption in 1990 was 64%. But the sector has a high energy intensity because most industries are still using old equipment in smaller plants that preclude economies of scale. The amount of energy required to produce a unit of steel, cement, ammonia, or paper is considerably more than what is required in industrialized countries (sometimes twice as much).

[3] Although the government decided to liberalize most energy prices at consumer levels, mixed price formulas continue to exist during the current transitional period. Up to the early 1990s, energy prices were so low that enterprises had little incentive to try to conserve energy. Low prices also constrained the development of new energy supplies.

[4] Final Energy Consumption is a measure of the actual commercial energy consumed by the end users. It does not include the generation or transmission losses that are included in Total Primary Energy Consumption, nor does it include non-commercial biomass fuels.

the standard breakdown into industrial, transportation, and agricultural sectors. The traditional commercial and residential sectors are combined into a single buildings sector when reporting results.

An energy intensity model was used to generate the projection. Energy intensity is the ratio of aggregate energy consumption to some aggregate measure of economic activity, typically GDP. Thus energy intensity may be interpreted as a measure of how much energy was consumed in any given activity versus the expense of the activity (similar to efficiency). By examining the history of a sector's energy intensity and GDP, and projecting that development into the future, energy requirements can be projected as the product of the intensity and sectoral GDP.

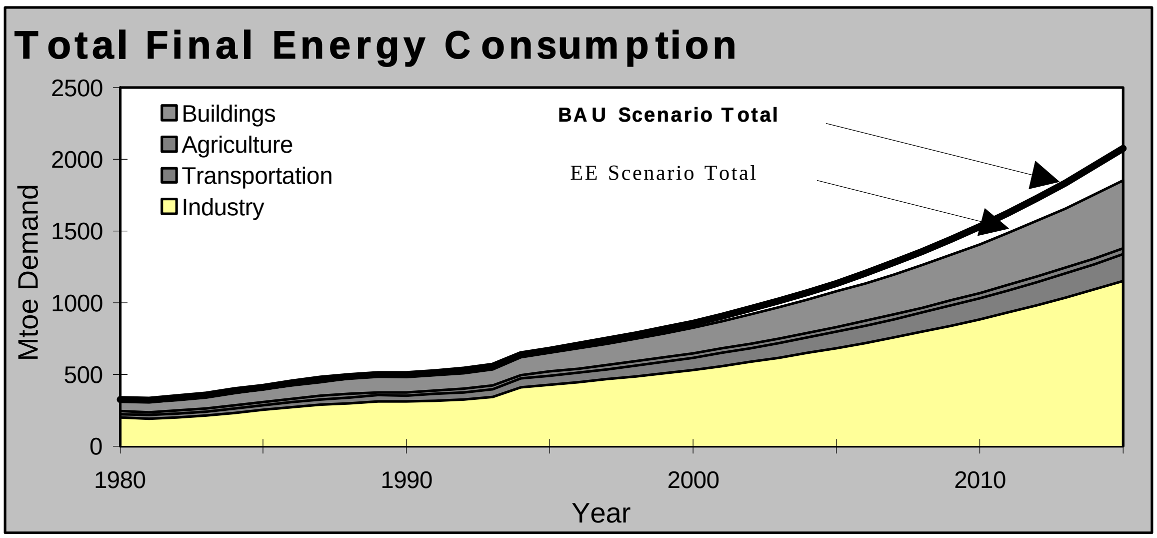


Figure 2

Source for historical data: IEA

Two scenarios are included in the analysis: a Business as Usual (BAU) scenario and an Energy Efficient (EE) scenario. The Business as Usual scenario projects future energy requirements based on current rates of development, assuming that past trends in consumption will continue. These trends were modified as necessary, by the following factors: 1) economic and social policies likely to affect future economic development and energy consumption; 2) trends in development and energy consumption for comparable countries at similar stages of development; and 3) trends in technology utilization and their implications for energy consumption. The Energy Efficient scenario assumes that the major consumption sectors of industry, transportation and buildings will reduce their energy intensity levels though increased use of energy efficient technologies. The agricultural sector was ignored for the EE analysis because the existing level of mechanization is so minimal that the BAU growth is considered to already be the most energy efficient option. In considering differences in fuel consumption, it is assumed that any reduction in demand between the BAU and EE scenarios will result solely in reduced coal consumption.[5]

[5] This assumption was made to match IEA data which indicates that current consumption efficiencies for hydropower, oil and natural gas resources are unlikely to be improved upon.

C. KEY FINDINGS

China is a large country in terms both of land mass and population, projected to grow 0.6% per annum (p.a.), during the next two decades. Given this population growth and industrialization/ modernization trends, energy consumption will increase substantially, as final energy requirements grow exponentially. We project the Chinese final energy requirement will grow by a multiple of 2.4 between 1994 to 2010 and 3.3 between 1994 to 2015, with average growth rates of 5% p.a. from 1994 to 2000, 5.9% p.a. from 2001 to 2005, 6.2% p.a. from 2006 to 2010, and 6.3% from 2011 to 2015. In other words, we project the Chinese final energy requirement will grow at an increasing rate in the next 20 years. A World Bank study projected Chinese energy demand will grow at an average rate of 6.5% p.a. while an IEA study projects energy demand will grow by a factor of 2.1 between 1993 and 2010, an average rate of 4.4% p.a. (Ishiguro, et al. 1995 & IEA 1996).[6] Our projections fall between the two.

Projected Energy Demand % Growth Rates					
Years	1994-2000	2001-2005	2006-2010	2011-2015	Demand in 2005
World Bank	6.5	6.5	n/a	n/a	1,267 Mtoe
IEA	4.4	4.4	4.4	n/a	987 Mtoe
BAU	5.3	6.0	6.4	6.6	1,136 Mtoe
EE	5.1	5.6	5.7	5.8	1,103 Mtoe

Table 1

1. The Business as Usual (BAU) Scenario:

Under the BAU scenario, China's total final energy requirement will increase by a factor of 3.3 to 2,077 Mtoe between 1994 and 2015, with a growth rates of 5.3% p.a. from 1994 to 2000, 6% p.a. from 2001 to 2005, 6.4% p.a. from 2006 to 2010, and 6.6% from 2011 to 2015 (Figure 2). In other words, we project that China's total energy requirement will grow in an increasing rate in the next 20 years.

The industrial sector will continue to be the largest energy user, but its share of final energy requirements will fall to 60% in 2015, down from the current value of 64% (Figure 2). Industrial energy intensity is assumed to continue decreasing at an ever decreasing rate as production shifts to high value-added and less energy intensive products, with anticipated improvements in technical and labor efficiency. Industry contributes 55% to the total GDP and it is assumed that the sectoral GDP will continue to grow faster than the total. Thus, the industrial sector will remain the dominant sector of the economy. It is projected that industrial final energy requirements will reach 1.24 billion toe (Btoe) in 2015.

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[6] The IEA study assumes that energy prices increase as demand increases, that energy conservation efforts made by the Chinese government will continue, and that the energy intensity will continue to drop. The World Bank projection, on the other hand, assumes limited energy conservation and a limited shift of products from high energy-intensive to lower ones.

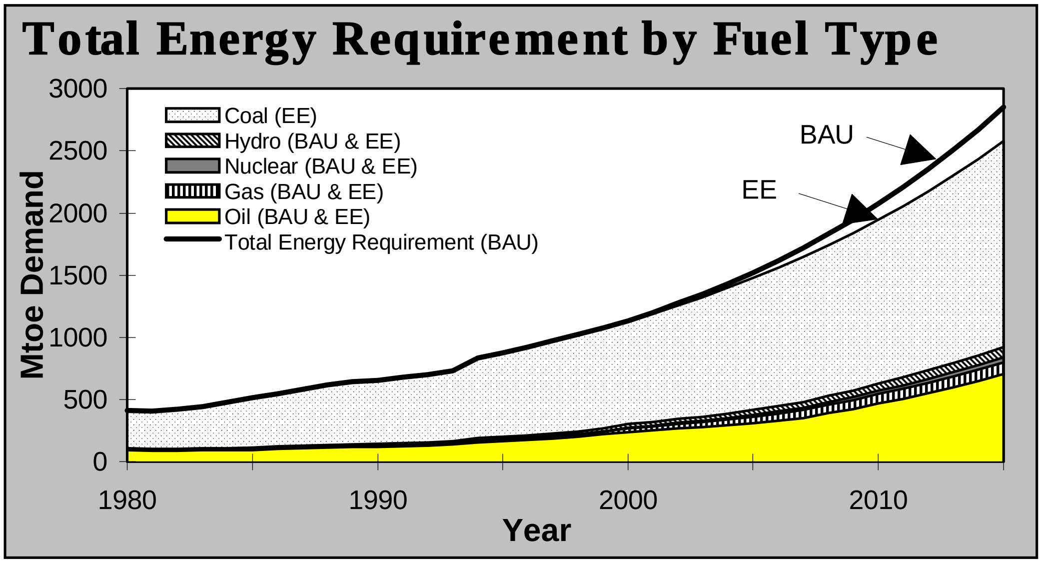

Figure 3 *Source for historical data: IEA*

Though certainly not the largest energy consumer, the commercial building sector is projected to have the largest increase in growth; final energy requirement will increase to 7.3% of the total, up from 2.7%, by 2015 (Figure 2). The reason for this sector's fast growth is that service sector GDP, the activity measure for the commercial buildings sector, will grow 11.1% p.a. Therefore, the service sector will grow from 25% of the economy in 1994 to 39% in 2015. With this growth will come an increase in energy consumption, and it is projected that the commercial sector's energy requirement will reach 151 Mtoe in 2015 (Figure 7).

Residential energy consumption in China is dominated by coal and biomass. However, since biomass is not a commercial fuel, it is not considered in our forecast. In consumption of commercial fuels, rapid economic growth has brought about significant changes in the consumption pattern. Most significantly, household use of electricity increased more than four-fold from 1980 to 1990, due to the increasing use of electric appliances. We project that the residential sector energy requirement will continue to increase, reaching 357 Mtoe in 2015 (Figure 7).

China is unlike other countries because its transportation infrastructure is so limited that this sector, typically a major energy consumer, makes up less than 10% of the total final energy consumption. Road traffic grew at a much faster rate than overall transportation, 13.3% p.a. increase for passenger road traffic while road freight grew at double the rate of rail freight. As a result, road passenger traffic as a share of all passenger traffic increased from 32% in 1980 to 49% in 1994. The tremendous increase in road usage spurred a 5.2% p.a. growth in energy consumption in this sector, but this is well below the total GDP growth of 10% p.a. Therefore the transportation sector's energy intensity has been decreasing. We assume the transportation energy intensity will continue to decrease, at a rate of 2% p.a. until 2005, and then at 1% p.a.

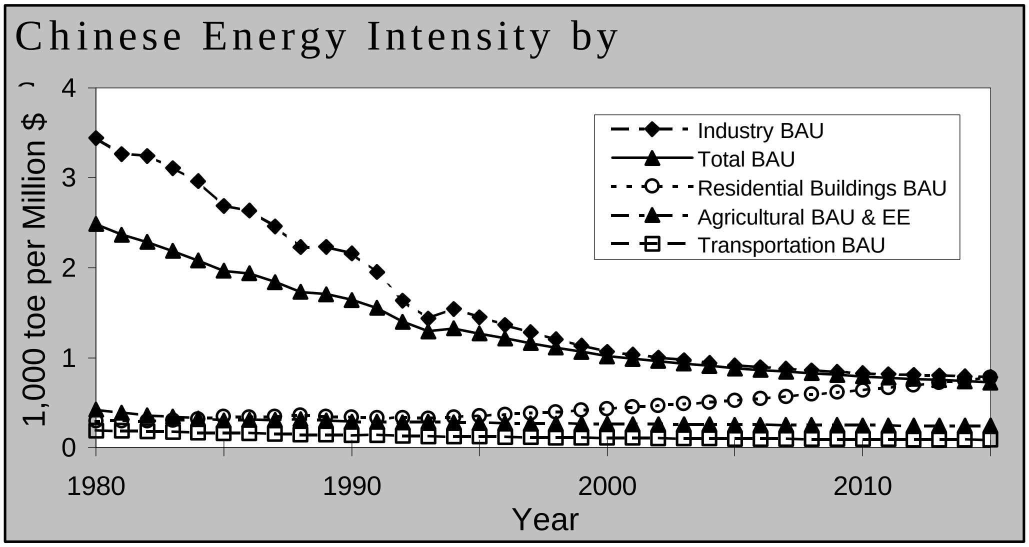

Figure 4 *Source for historical data: IEA, World Bank*

2. The Energy Efficient (EE) Scenario

Under the energy efficient scenario, total final energy requirement is projected to increase by a factor of 3.1 to 1,880 Mtoe with average growth rates of 5.1% p.a. from 1994 to 2000, 5.6% p.a. from 2001 to 2005, 5.7% p.a. from 2006 to 2010, and 5.8% from 2011 to 2015. In other words, even under the energy efficient scenario, we project that China's total energy requirement will still grow in an increasing rate in the next 20 years but will be slower than the BAU scenario.

Even under the EE scenario we don't expect the industrial energy intensity to drop much compared to the BAU scenario because the anticipated BAU 6% p.a. decrease is already a very high percentage for a developing country (IEA 1995). We assume the energy intensity will drop only 0.5% faster than the BAU scenario after the year 2000. It is estimated that under the EE scenario the industrial final energy requirement will reach 1.15 Btoe in 2015, just 95 Mtoe less than the BAU scenario. For the residential building sector, we assume the energy intensity increases 4% p.a. until 2005, just as it did in the BAU scenario, but then drops to 3% p.a. after 2005. With these constraints, the energy requirement will reach 324 Mtoe in 2015, 33 Mtoe less than the BAU scenario. For the transportation sector, we assume more steam locomotives will be replaced by more efficient diesel and electric locomotives, modern technologies will be imported to make the automobile fleet more efficient. This would allow the transportation sector energy intensity to decrease at a constant rate of 3% p.a. to 65 toe per million dollars in 2015[7], and the projected energy requirement will reach 186.9 Mtoe.

[7] Unless otherwise noted, dollars ($) in this text refers to constant 1987 US dollar value.

D. INDUSTRIAL SECTOR

Energy consumption in the industrial sector made up more than 61% of the total final energy consumption in China in 1993. The total industrial energy consumption increased from around 200 Mtoe in 1980 to 350 Mtoe in 1993. Currently, direct use of coal makes up almost 69% of all the final energy consumption, electricity 12.7%, and petroleum products 10.5%. The electricity share has been increasing quite rapidly while the share of direct use of coal has been gradually declining. The industrial energy intensity in 1993 was 144 toe/$ Million, much higher than the U.S. industrial intensity which was 52 toe/$ Million in 1970.[8] Energy intensity has been declining at an average rate of about 6% every year since 1980. However, at the same time the industrial GDP has been increasing at an average rate of about 10% every year.

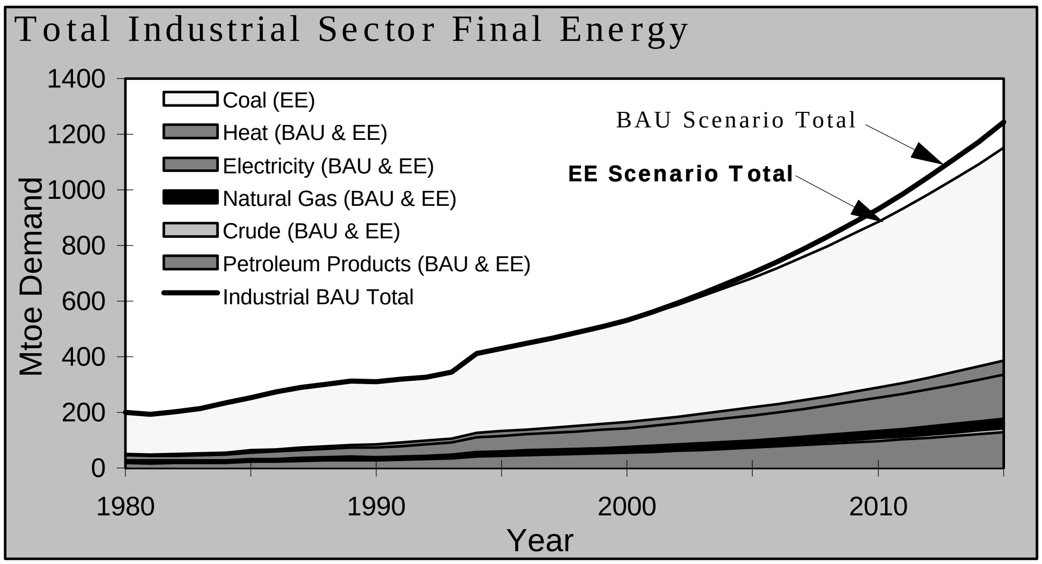

Figure 5

Source for historical data: IEA

Studies show that 80% of the reduction in energy-intensity between 1980 and 1985 is due to industry; of this 80%, 91% is due to efficiency improvement, and only 9% to structural change (Levine, et al. 1992). Because almost all energy savings in China occurred through efficiency gains in industry, the chemical, metallurgy and cement industries have been the major causes of China's reduced energy intensity in the early 1980s.

As indicated in the Ninth Five-Year Plan, adopted at the Eighth National People's Congress in March 1996, China intends to continue efficiency improvements through the restructuring of industry. Between the years 1996 and 2000, China will attach importance to the readjustment and optimization of the industrial structure, revitalizing pillar industries, and expediting the development of the tertiary sector (HKTDC 1995). The application of electronic information technology will be promoted, while the overall strength of the electronic industry is enhanced.

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[8] The market exchange rate was used to convert Chinese Yuan to US$; if a PPP exchange rate were used, the energy intensity for China would be lower.

The electronics industry is intended to become one of China's pillar industries. Special attention will be paid to microelectronics, as well as digital, software, and network technologies.

1. Analysis of three industrial sub-sectors

The fertilizer, iron and steel, and cement industries are analyzed briefly as typical examples of Chinese industry to measure energy consumption efficiencies. They represent the three largest industrial sub-sector consumers of the chemicals, ferrous metals, and building material production industries.

1-a. China's Fertilizer Industry

The largest energy consuming industrial sub-sector is China's chemicals industry, typified by fertilizer production. Since approximately 90% of the energy used in fertilizer production is consumed for generating ammonia from the catalytic fixation of atmospheric nitrogen. In the early 1960s China introduced a process to produce ammonia and ammonium bicarbonate from coal. Although this process is very energy inefficient and creates a low grade ammonium bicarbonate nitrogen fertilizer, it satisfied China's needs at that time. Many small plants using this technology were constructed and about half of China's nitrogen fertilizer comes from the 1,000 or so of these plants still in operation.

The low production efficiency is attributed not only to plant size but also to the feedstock used for ammonia synthesis. Whereas 98% of the feedstock in the United States is natural gas , coal is still used as the main feedstock in China.[9] Due to the abundance of coal reserves in China, old, small, coal-based plants still play a major role in the fertilizer industry. Modernization of these plants is necessary. However, many of the existing plants throughout the country remain strategically important because China's transportation infrastructure is not sufficiently developed to provide effective transport of fertilizer from the larger plants to rural China (Ishiguro, et al. 1995).

In March 1996 China unveiled a 15-year blueprint for the country's chemical industry calling for the expansion of chemical plants and increased foreign investment in the sector. The focal point of the plan will be chemicals for agricultural use, including fertilizers, pesticides, plastic film, and feed additives. (HKSTD, March 29, 1996).

1-b. China's Iron and Steel Industry

In 1994, the iron and steel industry produced 92.1 million tons of crude steel and rolled out 84.3 million tons of steel products, as well as significant amounts of cast iron. Total final energy consumption was 72 Mtoe in 1990, including 55.6 TWh of electricity and 56.6 Mtoe in combustible fuels. The steel industry accounts for 20% of total industrial fuel use, 14% of total industrial electricity use, and is the second largest energy user in China's industrial sector.

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[9] This high dependency on coal decreases the industry's overall energy efficiency. Coal-based ammonia production consumes about 35% more energy than gas-based with today's technologies.

Adjusted industry-wide, Chinese energy intensity in steel production was 35% higher than in the United States. Overall energy intensity has decreased with the reduced share of open hearth furnaces and increased use of continuous casting. However, some energy efficiency indicators have actually deteriorated in recent years as production from small plants increased[10]. The iron and steel industry in China has been targeted for energy conservation since the early 1980s, but due to the expense of conversion and the larger number of small plants, these plans have met with limited success (Ishiguro, et al. 1995).

China's crude steel production is expected to reach 172 million tons by 2005 and its potential imports of iron ore could reach 90 million tons compared to 37 million tons in 1993. China's iron ore imports are expected to rise to 56 million tons in 2001, while steel production is expected to rise to 95 million tons in 1996 (13% of world total) and to 114 million tons in 2001 (HKSTD, March 14, 1996).

1-c. China's Cement Industry

China is the world's largest producer of cement, generating about one-fifth of world total production. The 1990 output of 210 million tons doubled to 421 million tons by 1994. As with most Chinese industries, the bulk of production, 70%, is from small, inefficient, low capacity plants.

The cement industry consumed about 29 Mtoe of energy in 1990, accounting for 7% of total industrial final energy use. The two primary sources of energy were coal (77%) and electricity (23%). Energy accounts for about 40% of total production cost in China's cement industry, a dramatic indicator of the industry's inefficiency. Industry-wide fuel intensity for clinker making (the material ground into cement) is about 126 kg of oil equivalent (kgoe)/ton of clinker, whereas that of Japan s industry is 71 kgoe/ton of clinker.

Modernizing China's cement industry has been a unique endeavor because of the presence of so many inefficient vertical kilns. Conservation measures adopted by the industry in the 1980s included comprehensive retrofit of vertical kilns[11], conversion of wet process kilns to semi-dry or dry process kilns, and the introduction of large-scale precalciner kilns. Inefficient small plants were closed and wet and dry process kilns were also retrofitted (Ishiguro, et al. 1995).

2. Industrial Sector: Business As Usual Scenario

Industrial sector energy intensity is assumed to continue decreasing as it has for the past fifteen years, but at an ever decreasing rate. For the next five years, until 2000, energy intensity is

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[10] The industry average of the coke equivalent rate (fuel used to produce pig iron) rose from 605 kg/ton of pig iron to 611 kg/ton of pig iron between 1985-1990, and the industry average of electric arc furnaces (EAFs) intensity rose from 626 kWh/ton of crude steel to 689 kWh/ton of crude steel during the same period

[11] Advanced vertical kilns (VK) have a fuel intensity of about 88 kgoe/ton of clinker. The best-operated mechanized VKs can reach a fuel intensity of 77 kgoe/ton of clinker and an electricity intensity of less than 110 kWh/ton-of-cement. These figures indicate great potential for energy conservation in VK-equipped small plants, which now have an average fuel intensity of about 115 kgoe/ton of clinker.

assumed to decrease at the current rate of 6% p.a. From 2000 to 2005 it is assumed to decrease 3% p.a., 2% p.a. from 2006 to 2010, and 1% p.a. from 2011 to 2015 (Figure 4).

The energy intensity will keep decreasing for three major reasons. Improvements in technical efficiency, and changes in the relative output of major industries, including a shift from heavy to light industry. Also, China is starting to use its labor resources more wisely, increasing labor efficiency instead of merely relying on the large volume of the available labor pool. In other words, China intends to manufacture high value products that require small amounts of energy to produce. The rate of improvement is expected to drop as these changes take place and the desired efficiency is achieved.

Chinese Industrial Development		
EFFICIENCY IMPROVEMENTS	SHIFT TO LIGHT INDUSTRY	BETTER USE OF LABOR
• New boilers • Better electric motors • Computerized process control	• Move to electronics from heavy machinery production	• Reduce dependence on labor pool volume • More efficient use of labor

Table 2

China will renovate traditional industries by upgrading 70% of all industrial boilers and high consumption electric motors. Efficiency increases are expected from computer control of both process, to be introduced in 14,000 factories, and through use of computers to improve labor efficiency. In medium and large sized enterprises, computer aided design will be used in 70% of the designing work, while in a simultaneous effort to improve finances, computers will be introduced to manage more than 5,000 additional plants. Lastly, a shift in production is expected to cause the heavy to light industry ratio to drop from 57:43 to 50:50 as the electronics and communications industries grow.

We assume the intensity will decline to 787 toe/$ Million[12] by the year 2015 (still higher than the U.S. industrial energy intensity in 1973, which was 500 toe/$ Million). We assume the industrial GDP will grow at an annual rate of 11% until 2000, and 9% p.a. from 2001 to 2005, 8% from 2006 to 2010, 7% from 2011 to 2015 (Figure 6). Industrial GDP is assumed to grow faster than total GDP because industrial GDP made up over 55% of the total GDP and with all these efforts in developing the industrial sector, it will remain the leading sector of the future economy in China. Growth in industrial GDP and reductions in energy intensity imply that the industrial final energy requirement will increase and reach 1.24 Btoe in 2015 (Figure 5).

3. Industrial Sector: Energy Efficient Scenario

Under the EE scenario, we expect the energy intensity to drop about the same as in the BAU scenario, because the BAU 6% p.a. decrease is already very high for a developing country (IEA 1995). Therefore, we assume that under the EE scenario the energy intensity will decrease at the BAU rate of 6% p.a. until the year 2000. From 2000 to 2005, it is assumed to drop 3.5% p.a.,

[12] Unless otherwise noted, all dollar amounts are in constant 1987 dollars.

2.5% p.a. from 2006 to 2010, and 1.5% p.a. from 2011 to 2015. This is only 0.5% faster than in the BAU scenario. Industrial GDP is assumed to growth the same rate as it is in the BAU scenario. Thus, under the EE scenario, the industrial final energy requirement will reach 1.15 Btoe in 2015, 95 Mtoe less than the BAU scenario (Figure 5).

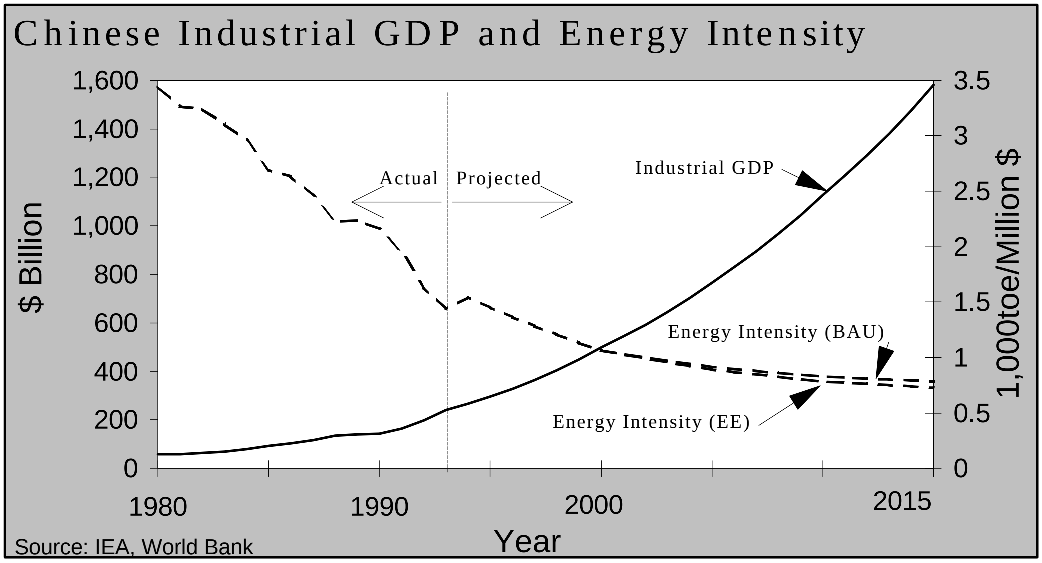

Figure 6 *Source for historical data: World Bank, IEA*

E. BUILDING SECTOR

Total building energy consumption increased from around 67 Mtoe in 1980 to about 113 Mtoe in 1993 and made up more than 20% of the total final commercial energy consumption in China. It is second only to the industrial sector in terms of energy consumption (Figure 2). Of the 20%, over 87% (98.6 Mtoe) was for residential buildings, excluding biomass.

Although the commercial and residential sectors have been combined in our treatment of the building sector, the two have very different fuel consumption characteristics. Household, or residential energy consumption is predominantly fuels for cooking and space heating, while commercial consumption shows a higher dependence on the petroleum products and electricity needed to run a modern business. In residential consumption, seventy percent of the population lives in rural areas where commercial fuels are scarce; up to eighty percent of the residential fuel use is non-commercial biomass, mostly crop stalks and firewood (Ishiguro, et al. 1995). So much non-commercial fuel is used in the residential sector that biomass use in 1993 was over 54 Mtoe, three times as much as the energy used in commercial buildings (LBL 1996).

In urban areas where commercial fuels are more accessible, coal dominates the residential energy market. However, with rapid economic growth, urban energy consumers have begun to use electricity both to run new appliances and as a coal substitute. Consequently, household electricity demand increased five-fold from 1980 to 1993. In 1993, direct use of coal made up over 85% of the energy used in the residential building sector, electricity 8%, and petroleum products 4%. The use of fuel for the commercial building sector is very different. Direct use of coal made up less than 35% of the energy used in the commercial building sector while electricity made up over 40%, and petroleum products more than 25%.

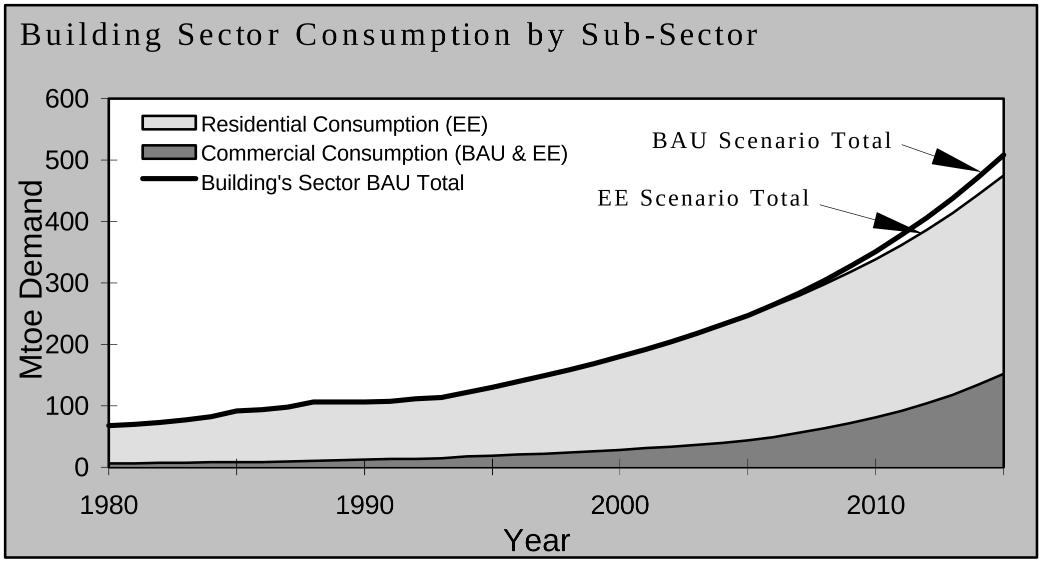

Figure 7 *Source for historical data: IEA*

Gas fuels for cooking (about half being LPG) are much more accessible in urban Chinese households, with nearly 60% of residents in cities now having access. The rate of gas fuel consumption has been rising as fast as electricity, as cities nationwide push to improve the efficiency and cleanliness of household cooking fuel use. LPG demand growth, concentrated in the coastal area south of the Yangtze River, has made China a net importer. Gas fuels are still virtually unavailable in rural areas (LBNL, 1996).

Possession of Appliances per 100 households in 1994		
Appliance Type	Urban Household	Rural Household
Electric Fan	153.79	80.91
Color TV Set	86.21	13.52
Refrigerators	62.10	4.00

Table 3   Source: *China Statistical Yearbook 1995*

There are significant differences in the quality of energy service between rural and urban households, sharply differentiated into those who have electricity and those who have not.   While urban households have adequate fuel supplies and access to electricity, many rural areas still suffer from fuel shortage. About 40 million rural households, out of 232 million, have no access to electricity. Per capita fuel consumption in rural areas is higher than in urban areas because of inefficient use of biomass, while per capita electricity use in urban areas is four times as much as their rural counterparts from much higher rates of appliance use.

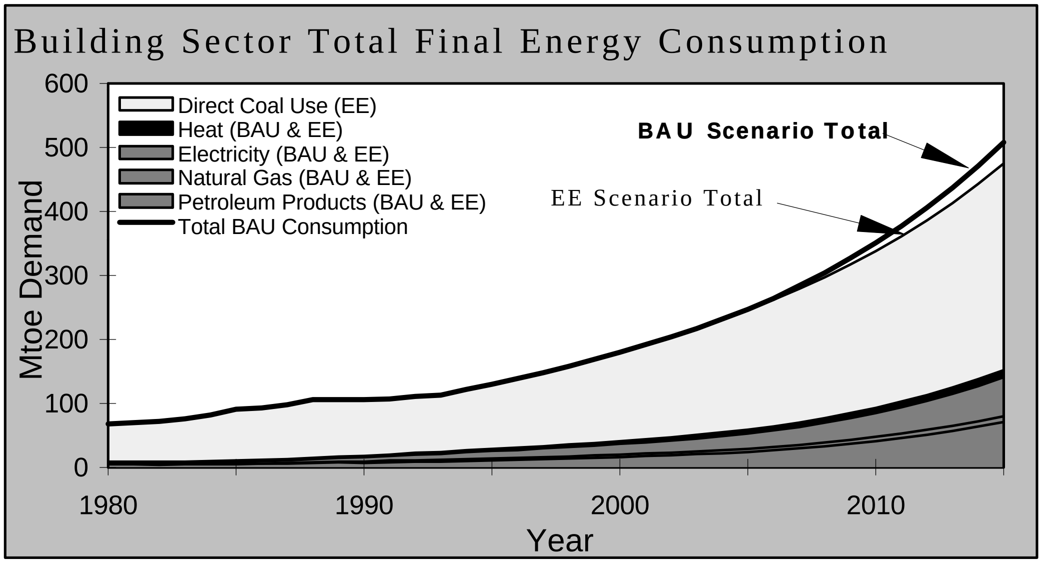

Figure 8 *Source for historical data: IEA*

According to the Ninth Five-Year Plan, China will accelerate the establishment of large regional electric power grids in accordance with the development strategy of transmitting power from central to eastern China, laying the foundation for the formation of a national grid (HKTDC 1995). It is likely that when electricity is more readily available to the households in the rural areas, electricity demand in the residential sector will increase significantly.

1. Buildings Sector: Business As Usual Scenario

Residential building energy intensity is defined as energy used (commercial energy, i.e. excluding biomass) divided by the number of households. In 1993, the energy intensity was 0.33 toe/household and has been increasing steadily over the years (Figure 10). One would expect once households have basic appliances such as lighting, fans, TV sets and cooking ranges, the energy intensity will level off. However, China has a huge rural population; their basic needs are not yet met. Therefore, when electricity is made available to them, more basic appliances will be added to the households and electricity consumption will increase to the point where all available supply is in use; hence, the energy intensity increase in rural areas will offset any urban decreases.

Commercial building energy intensity is defined as total energy used in the commercial sector, divided by service sector GDP. In 1993, the energy intensity was 142 toe/$ Million, and has been slowly decreasing. The service sector in China is growing rapidly, even faster than the industrial sector, at a rate of over 11% in 1993. The growth rate of the service sector is faster than the growth rate of energy consumption, thus, energy intensity is decreasing (Figure 9).

In our BAU scenario, we assume residential energy intensity increases at a rate of 4% p.a. until the year 2015 with a constant 7174 households added per annum. For demand forecasting, the projected number of households is used rather than a sectoral GDP as an activity measure. In 2015, the projected energy intensity will be 0.78 toe/household (Figure 10). The U.S. residential energy intensity in 1980 was 2.25 toe/household. It is projected that the residential sector energy requirement will reach 357 Mtoe in 2015 (Figure 7).

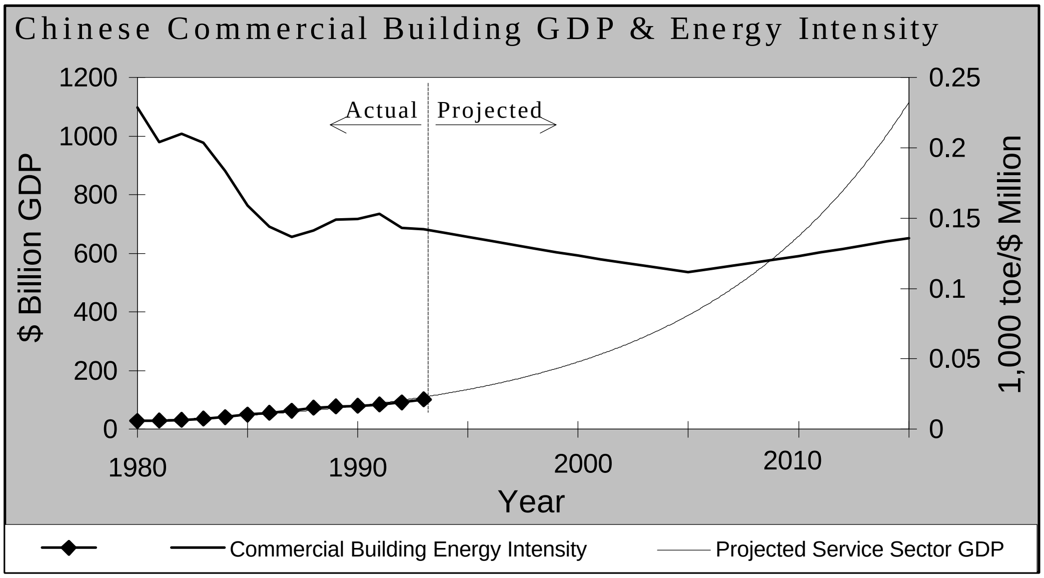

Figure 9 *Source for historical data: World Bank, IEA*

For the commercial buildings sector, service sector GDP will grow 11.1% p.a. It is assumed that commercial energy intensity will decrease 2% p.a. until 2005, after which the intensity will increase 2% p.a. (Figure 9). This reversal of trends is ascribed to the theory that as an increasing number of service sector businesses open, and the service supply catches up with demand, the value of services provided by the commercial sector will not grow more slowly than in the recent past. Thus, energy intensity will increase as operational costs rise through the addition of electronic office products such as copiers and computers, while the value of the services remains constant. Given these fluctuations, the commercial building energy requirement will reach 151 Mtoe in 2015 (Figure 7).

2. Buildings Sector: Energy Efficient Scenario

In our EE scenario, residential energy intensity increases by 4% p.a. until 2005, just as in the BAU scenario, but then the growth rate drops to 3% p.a. after 2005. The household growth rate remains constant at 7174 p.a. for both the BAU and EE scenarios. Under the energy efficient scenario, energy intensity will increase to 0.71 toe/household and the energy requirement will reach 324 Mtoe in 2015, 33 Mtoe less than the BAU scenario (Figure 7).

Commercial buildings account for less than 3% of the total final energy demand in China in 1993, which is insignificant compared to other sectors. Thus energy-efficient commercial appliances will not make much difference to the total future energy requirement in China, and the EE scenario is assumed to be the same as the BAU scenario for commercial buildings at 151 Mtoe.

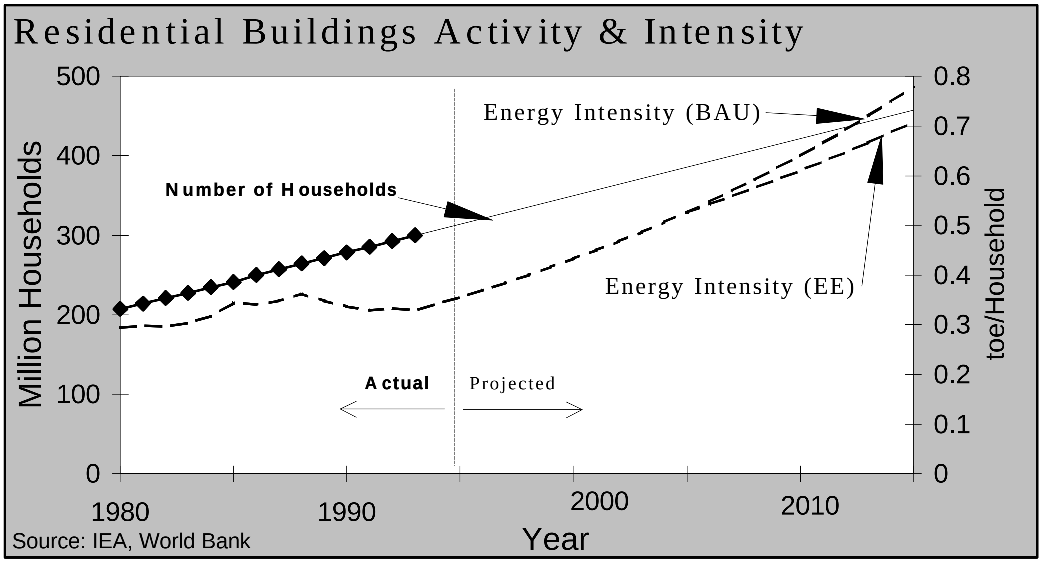

Figure 10 *Source for historical data: World Bank,*

F. TRANSPORTATION SECTOR

Energy consumption in the transportation sector made up less than 10% of the total final commercial energy consumption in China in 1993, just one-sixth of the industrial sector's total (Figure 2). Of this, the majority is for road transportation (65%), while less than 3% was for air transportation and slightly over 3% was for domestic waterway navigation. The remainder was used for rail transportation (Figure 11).

This amazingly low percentage of the transportation sector energy consumption is a direct consequence of Mao's "Country Planning" in the 1950's. Fearing invasion by the Soviet Union, Mao spread Chinese industries to isolated villages, with minimal road connections. Each of these isolated villages was intended to be self-sufficient. Long-distance transportation has only recently become a priority.

The total transportation energy consumption more than doubled to 56 Mtoe between 1980 and 1993. The average energy consumption growth rate of the transportation sector was 5.2% p.a. between 1980 and 1993, and thus was higher than the growth rate of total final energy consumption (4.7% p.a.) but was a lot lower than the average 10% p.a. GDP growth rate. Therefore, transportation sector energy intensity in China has been decreasing.

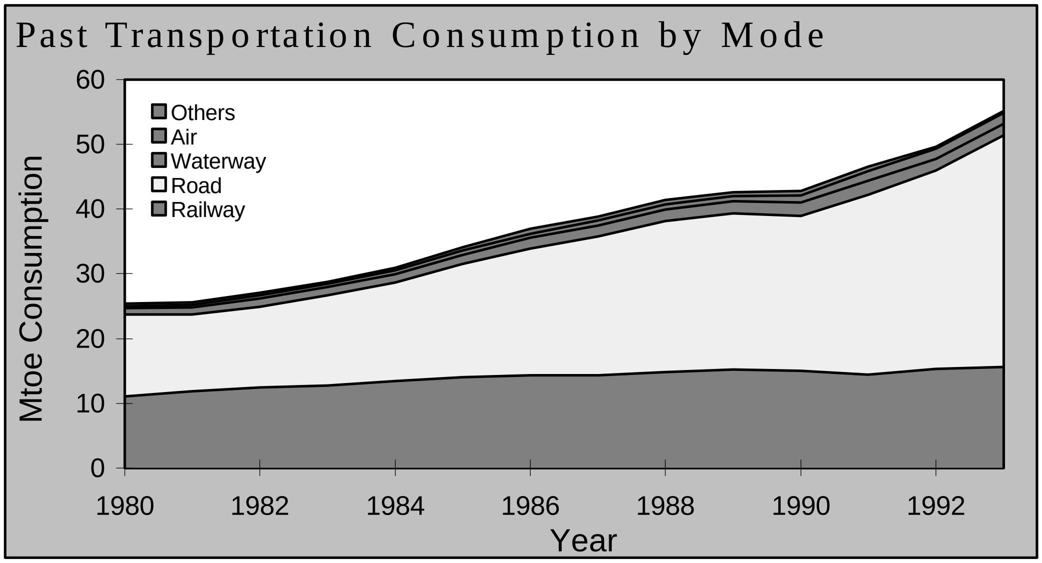

Figure 11 *Source for historical data: IEA*

1993, petroleum products made up over 78% of all the final energy used in this sector (coal made up 18.7% and electricity made up 2%) (Figure 12).

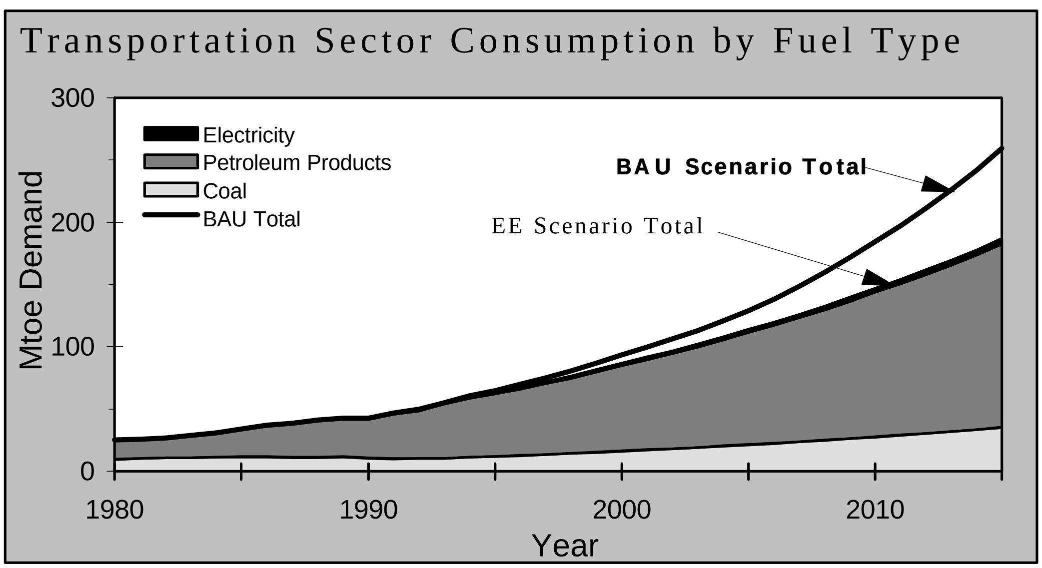

Figure 12 *Source for historical data: IEA*

1. Road Transportation

The energy consumption of road transportation increased to 35.9 Mtoe in 1993, the growth rate being a substantial 7.5% p.a. between 1985 and 1994. However, the energy efficiency of road transportation in China is increasing; during the 1980s almost all of China's domestic car makers imported modern technologies from western auto-makers through technology transfer agreements.

The growth rate of cars in use was more than 20% p.a. between 1985 and 1994. The total number of motor vehicles, estimated at 3.2 million in 1985, is projected to quadruple by the year 2000. China's demand for all kinds of motor vehicles will increase steadily over the next five years, at an average annual growth rate of 7 to 8 % (HKSTD, April 8, 1996).[13]

According to the Ninth Five-Year Plan, China is expected to manufacture 2.7 million new automobiles by the year 2000, which will meet 90% of the domestic demand.[14] It is estimated there will be a market for about three million cars by 2000, with demand reaching five to six million by 2010. (HKSTD, March 15, 1996). However, recent reports show that China's automobile production, aimed at private ownership, is faltering. Due to the expense, the vast majority of cars are being bought with state money. Of the 1.6 million cars on China's roads, only 50,000 cars or 3% are owned by private individuals. With newly imposed caps on state automobile purchases, analysts fear that the private car market will not live up to expectations as private sector purchases cannot make up for the shortfall in public spending, due to high prices, high license fees, and legal restrictions on ownership[15] (HKSTD, April 19, 1996).

2. Railway Transportation

Between 1978 and 1994, the total length of China's railway track increased from 48,000 km to 53,992 km, with the length of double-tracked railways expanding from 7,630 km to 16,159 km, and that of electrified railways from 1,030 km to 8,966 km. The volume of passengers increased by a factor of 2.6 between 1980 and 1994, while freight volume increased by a factor of 2.2. In 1994, the railways carried 1.89 billion passengers and 1.57 billion tons of cargo.

The replacement of old steam locomotives with diesel and electric locomotives was promoted strongly during the late 1980s. By 1993 the combined capacity of electric locomotives was over 7 GW, compared to less than 2 GW in 1986 (LBNL 1996).

As steam locomotives have been retired and replaced with new engines, the pattern of rail energy consumption has changed. Electricity and oil consumption doubled as diesel and electric engines became more common. However, coal still dominates fuel consumption at 66%, compared to 27% for oil and 7% for electricity.

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[13] By the year 2000, annual demand is forecast at three million vehicles while local output is expected to amount to only 2.7 million.

[14] To attain the target, emphasis would be placed on the development of auto parts and components, economy cars, and heavy-duty trucks.

[15] The cost of license plates in the city, sold at auctions, was almost the same as that of a private car. The high cost of the license plates aims to control private purchase of cars on the streets of Shanghai and other major cities, which are already crowded with bicycles, buses, motorcycles, and trucks. License plates in Shanghai for any private car costs about 140,000 yuan, while a four-seater Santana costs about 170,000 yuan and a Daihatsu Charade about 100,000 yuan. The average Shanghai worker earned 9,242 yuan in 1995, an inflation-adjusted increase of 5.2% on 1994.

3. Air Transportation

Boeing estimates that China will have the world's largest rate of air travel growth, an average of 11.5% annually over the next 20 years. In its latest aviation market outlook, Boeing said the worldwide average rate of increase for the same period was 5.1%. Travel in the Asia-Pacific region is expected to grow the fastest at 7.1%. By 2015, Boeing predicted traffic in Asia would be equal to that of North America as both regions post an average annual growth rate of 7.1% (HKSTD, March 8, 1996).

4. Transportation Sector: Business As Usual Scenario

The transportation energy intensity (total consumption divided by sectoral GDP) has been decreasing at an average rate of 3.5% p.a., despite the fact that energy consumption in this sector has been growing at a rate of 5.2% p.a. and the sectoral GDP grows much faster at a rate of 10% p.a. We assume the transportation energy intensity will continue to drop at a decreasing rate; 2% p.a. until 2005, and 1% p.a. until 2015. This projection puts the transportation sector energy intensity at 90 toe/$ Million and the total energy requirement at 259.2 Mtoe in 2015 (Figure 12 & 13).

5. Transportation Sector: Energy Efficient Scenario

Under the EE scenario, we assume a larger fraction of currently operating steam locomotives will be replaced by diesel and electric engines, and that implementation of modern technologies will make the automobile fleet more efficient. Therefore, in the EE scenario, energy intensity will decrease at a constant rate of 3% p.a.. This projection puts the transportation energy intensity at just 65 toe/$ Million and the projected energy requirement at 186.9 Mtoe in 2015 (Figure 12 & 13).

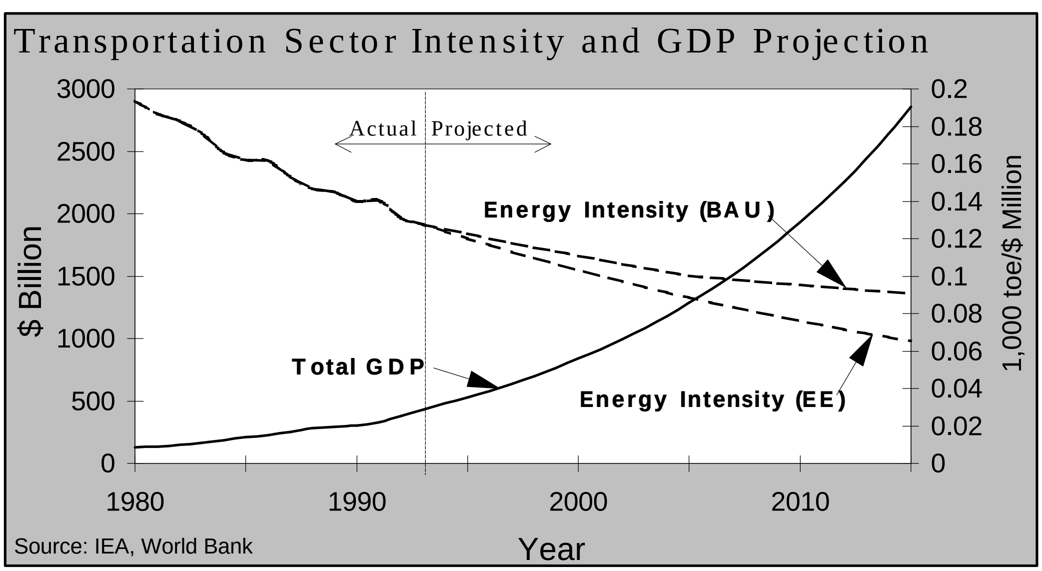

Figure 13 *Source for historical data: World Bank, IEA*

G. AGRICULTURAL SECTOR

Agriculture is the smallest sectoral user, consuming less than 5% of the total final commercial energy in 1993. Direct use of coal made up almost 44.5% of the total final energy used, with petroleum products and electricity being the only other fuel sources at 37.6% and 17.9% respectively. Electricity has been gradually replacing direct coal consumption, and its share has been increasing.

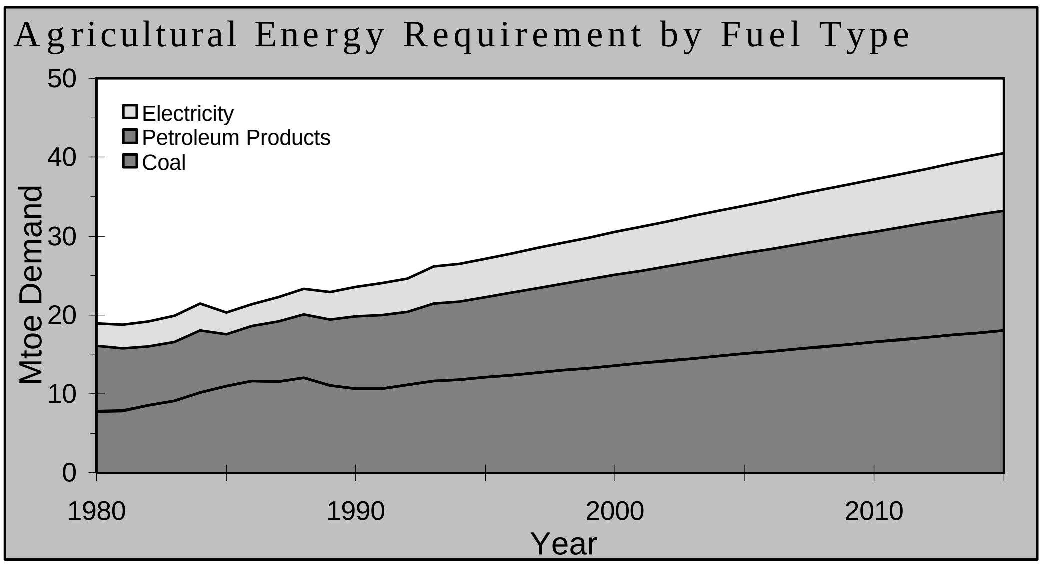

Figure 14 *Source for historical data: IEA*

China has been sacrificing farmland to industry, and is facing a serious food supply problem. With its grasslands already overgrazed beyond their sustainable capacity, livestock must be fed grain, pushing grain demand up dramatically.[16] In fact, China has become the world's largest wheat importer[17] (HKSTD, April 1, 1996). Further, as food imports become accessible, the Chinese are switching from their traditional grain-based diet to one based on meat and dairy products, making China the new world leader in the consumption of pork (Worldwatch Institute, 1995). The Worldwatch Institute has said that by 2030 China could face a deficit of between 200 and 365 million tons in grain needed to feed 1.6 billion people by that time, warning that this would put severe strains on international stocks.

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[16] If per capita grain consumption rises from just under 300 kilograms in the mid-1990s to 400 kilograms in the year 2030, about the current level in Taiwan, total demand will climb more than 79%.

[17] Last year, China imported 11.59 million tons of wheat, and purchased more than half a million tons in January 1996 alone. As China's target for wheat harvest this year remains at last year's level, the International Grains Council projected Chinese wheat imports to 14 million tons for the July 1996 to June 1997 season, a rise of one million tons from 1995-1996.

Chinese officials say their primary strategy in the 1990s will be to raise yields on less productive land by increasing the use of fertilizer and high-yield seeds. Moves to protect arable land from encroachment by industrial development will be intensified, reserves of farm products built up, science and technology applied to optimize yields, side-line industries developed, product varieties adjusted, and overall rural reforms deepened (HKSTD, March 8, 1996).

China hopes to squeeze out badly needed gains in agricultural efficiency by increasing mechanization and encouraging coordination among farms. While efforts to boost output have focused in recent years on easy credit and other incentives, the emphasis now will be on aiding grain production centers and the farm machinery sector.[18] (HKSTD, March 4, 1996).

1. Agriculture Sector: Business As Usual Scenario

Although the Chinese government is working to mechanize their agricultural sector, heavy machines may not work well in small farms. China's millions of tiny family farms average only 0.46 hectares in size each, so large scale western mechanization techniques have limited applicability. Moreover, urban industrial salaries are growing much faster than farm earnings, and there has been a mass migration of peasants leaving their farms for the cities.

Crime rates increased significantly in all Chinese cities in recent years because of these unemployed peasants, and the crimes committed are becoming more and more serious. Fighting the crime rate has become another "priority" in the Ninth Five-Year Plan. Therefore, in the coming years, Beijing would need to either find work for these peasants in the cities or keep them on the farms. Currently, over 54% of the labor force in China are farmers. With this huge labor force and the social reasons to keep peasants on farms, the practicality of mechanizing the agricultural sector remains to be seen.

Since the agricultural energy demand accounted for less than 5% of China's total final energy consumption in 1993, no reasonable scenarios would have any significant impact on the total energy requirement projection. Therefore, we fit a regression line to the historical data to the project the future energy intensity and agriculture GDP. The result shows agriculture GDP will grow $3.4 billion p.a. and the energy intensity will decrease at a decreasing rate from 0.94% in 1994 to 0.44% in 2015 (Figure 15). Thus, projected energy requirement for the agricultural sector will increase from 26.5 Mtoe in 1994 to over 40.5 Mtoe in 2015 (Figure 14).

2. Agriculture Sector: Energy Efficient Scenario

[18] The State Council, China's cabinet, issued an eight-point decree calling on officials nationwide to help farmers carry out their spring planting to assure a good 1996 harvest. China, crisscrossed with millions of tiny, inefficient family farms averaging only 0.46 hectares each, set up the grain production center system in 1983 as a means of streamlining agricultural output. The centers help organize individual farms, providing technical training and field management and sponsoring seed reserves and breeding projects. Only 38% of China's farms are affiliated with the centers, which account for 46.6% of total grain output and produce an average of 0.8 of a ton more per hectare than the national average.

We assume the EE scenario is the same as the BAU scenario because China is still in an early stage of mechanizing its agriculture sector. Even if we assume china were able to successfully mechanize its farms in the next 25 years, primary effort will have to be focused on increasing production. Moreover, machines are an expensive capital investment and once they are purchased, it will take some time before they will be replaced with more efficient equipment again.

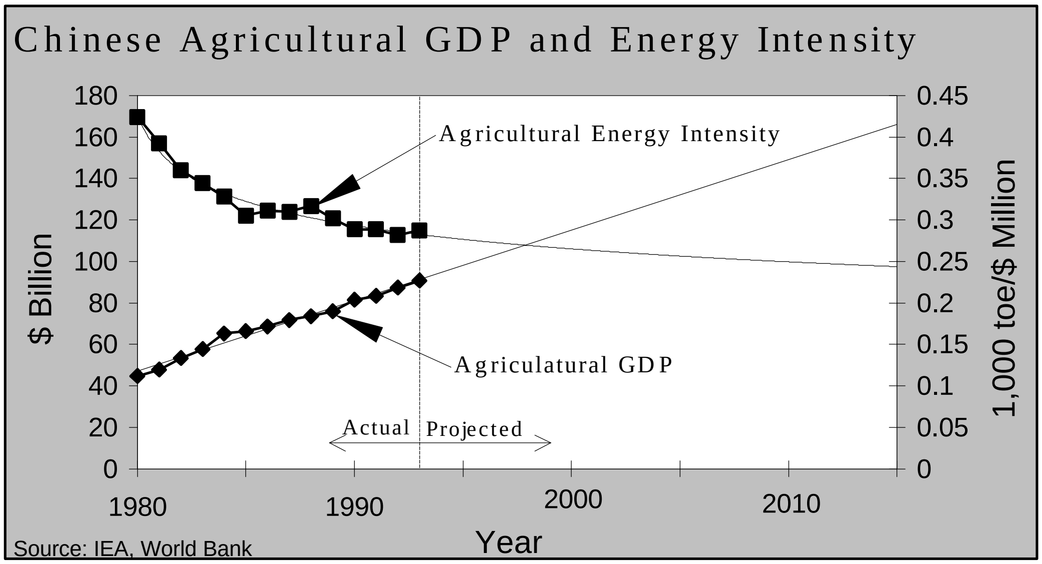

Figure 15 *Source for historical data: World Bank, IEA*

H. OTHER USES SECTOR

Energy consumption for other uses made up less than 3.6% of the total final energy consumption in China in 1993 (Figure 5) and is not identified as a sector in Figure 1. The total “other” energy consumption increased from 13.9 Mtoe in 1980 to about 20 Mtoe in 1993. Direct use of coal made up almost 52.5% of all the final energy used in this sector, petroleum product 45.5% and heat 2% (Figure 16).

1. Other Users: Business As Usual Scenario

Again, since the other uses sector accounted for less than 3.6% of China’s final energy consumption in 1993, it is unreasonable to assume that this sector will have any significant impact on the total energy requirement projection. Therefore, the forecast was made by fitting a regression line to the historical data to get the projection for energy intensity. Energy intensity here is defined as the energy consumption divided by total GDP. The result shows energy intensity will decrease 7% p.a. The total GDP is assumed to grow 10% p.a. before 2000 and gradually grow at a decreasing rate (Figure 17). Therefore, the projected energy requirement for the others sector will increase from 20.8 Mtoe in 1994 to over 26.9 Mtoe in 2015 (Figure 16).

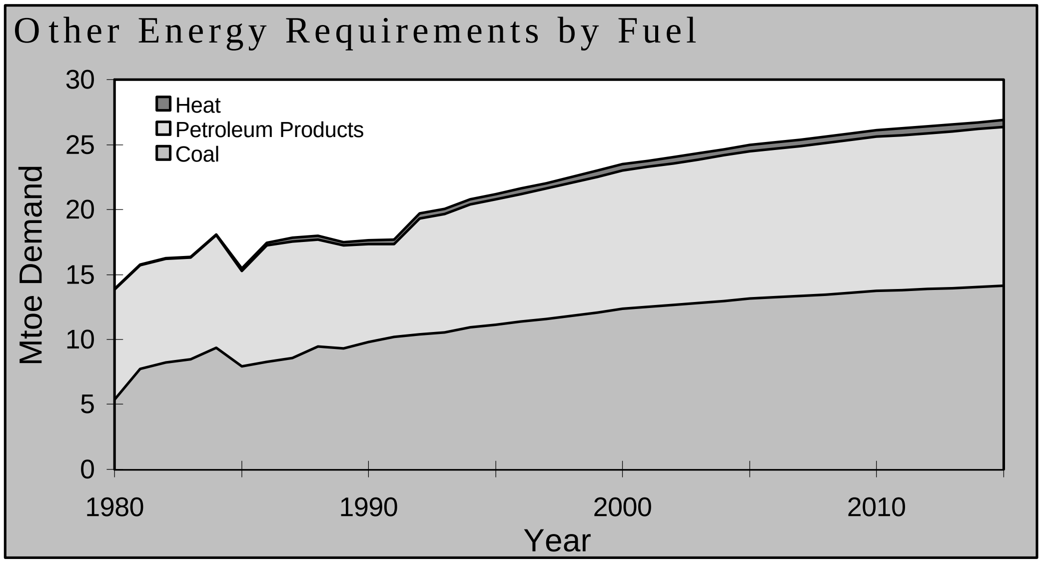

Figure 16

Source for historical data: IEA

2. Other Users: Energy Efficient Scenario

We assume the EE scenario is the same as the BAU scenario. As mentioned above, the others sector energy demand accounted for less than 3.6% of China's final energy consumption in 1993, improvement of energy efficiency in this sector is not expected to have any significant impact on the total energy requirement projection.

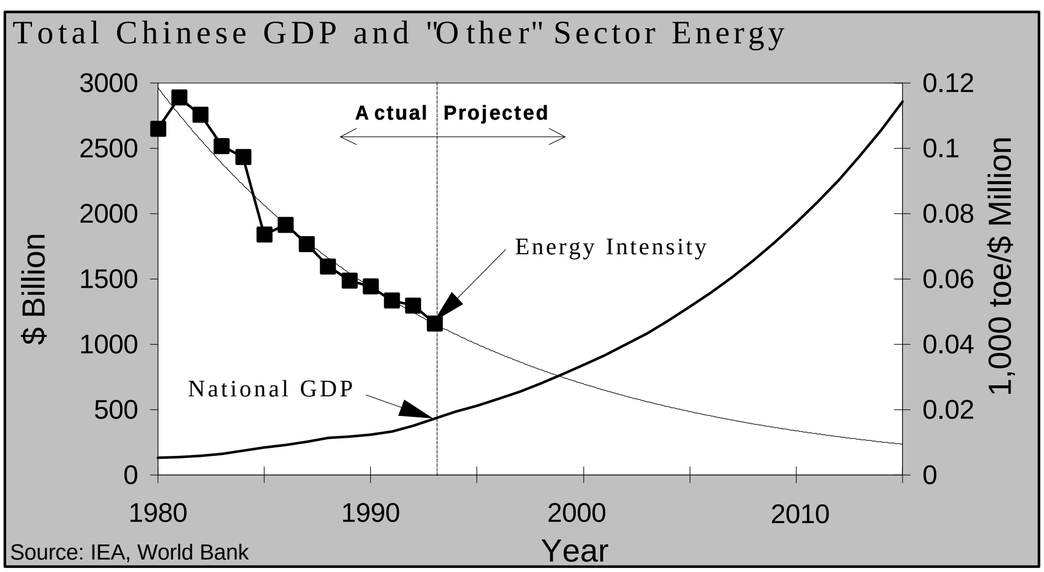

Figure 17

Source for historical data: World Bank, IEA

I. CONCLUSIONS

Chinese final energy requirements will reach between 2,853 Mtoe (BAU) and 2,581 Mtoe (EE) in 2015, depending on which scenario is considered. However, the structure of energy fuel consumption will remain relatively unchanged, despite the demand for new energy sources in urban areas and an increased production of electricity. As now, the majority of consumption will be in the industrial sector, followed by the consumption in buildings and transportation. Coal will remain the dominant energy source at 64%, followed by oil at 27% and natural gas at just under 4 %. What will change dramatically is the total consumption, up 334% from 1994. This increase will severely strain domestic energy resource supplies, and if China chooses to import resources in an effort to compensate, the volume of imports may cause increases in world energy prices, and indirectly affect US energy security (*see Summary, Section I)*.

APPENDIX

CHINA'S NINTH FIVE-YEAR PLAN

The Following contains translated excerpts from the ninth Chinese "Five-Year Plan", describing proposed development and growth for the years 1996-2000. It is provided here to give interested readers a direct listing of what the Chinese intend to do; following the philosophy that the best sources of intelligence on Chinese intentions, is the Chinese government.

The priorities in China's Ninth Five-Year Plan for industrial development and the readjustment of the industrial structure are to:

1. Strengthen water conservancy construction, maintain steady agricultural growth, and promote all-round development of the rural economy

2. Speed up the development of basic industries and infrastructure facilities by launching a number of key projects related to the construction of railways, ports, highways, airports, petroleum plants, coal mines, chemical plants, and iron and steel works

3. Transform and reorganize the light and textile industries by raising their technological level and improving the quality and grade of their products

4. Actively invigorate the pillar industries (the electronics industry should focus on developing integrated circuits, computers and telecommunications equipment; the petrochemical industry should focus on the production of ethylene; the automobile industry should focus on the production of sedans, lightweight vehicles, as well as parts and components; the building industry should focus on the construction of residential housing, public facilities, and industrial facilities, as well as the development of new building materials)

5. Accelerate the development of the tertiary industry, and establish a healthy market system and a community service and social security system

6. Strengthen the development and application of technologies crucial to economic and social development, and promote the translation of research results into real productive forces.

During the Ninth Five-Year Plan (1996-2000), China will strive to increase the annual output of raw coal to 170-220 million tons. The construction of coal mines will be accelerated[1]; the policy of opening the coal industry to the outside world will be continued; and departments in the power, metallurgical, and other industries will be encouraged to invest in mines to produce new sources of capital. Foreign enterprises will also be welcome to engage in mining in China through equity and contractual joint ventures or other modes.

The industrial structure will be readjusted in accordance with the idea of comprehensive development and diversified operation. Coal-mining enterprises will be encouraged to build coal washing and dressing plants, as well as power plants, coking plants, and coal-chemical plants. These enterprises will also be encouraged to exploit

[1] In the development of state-owned coal mines, priority will be given to seven large open-pit mines, including those at Pingshuo, Shenfu, Dongsheng, and Jungger. In the development of local state-owned mines, work on 15 commodity-coal production bases at Xinji, Jixi and other places will be expedited. At the same time, attention will be paid to the development of 100 major coal-producing counties in an effort to transform and upgrade the existing township mines.

and utilize their regenerative coal resources, and to promote the simultaneous development of coal-mining, power generation, and road and port construction where conditions are favorable. A variety of cooperative avenues will be adopted to pool funds for the construction of a number of large energy bases that combine coal transportation with power transmission meeting the needs of the country. Government discount credit will be used to expedite the development of key multi-function projects (HKTDC 1995).

In order to attract foreign investment, the State Planning Commission has drawn up regulations to govern "build, operate, and transfer projects" (BOT) and submitted them to the State Council for approval. Under a BOT agreement, the government authorizes an investor to build a project and operate it for a set period of time, after which ownership and rights revert to the government.

A temporary BOT administration regulation was issued last year by the commission, the Ministry of Communications and the Ministry of Power Industry. Under the regulation, the BOT method is confined to infrastructure projects, including hydroelectric power plants with a capacity of at least 250,000 kilowatts per hour, thermal power plants with a capacity above 600,000 kilowatts, high-grade roads 30-80 kilometers long, bridges and tunnels more than 1,000 meters long, and urban water supply plants (HKSTD, March 26, 1996).

According to China's Ninth Five-Year Plan, China will make the automobile industry one of their backbone industry. China is expected to produce 2.7 million automobiles, which can meet more than 90% of the domestic demand by 2000. To attain the target, emphasis would be placed on the development of auto parts and components, economy cars, and heavy-duty trucks. It is estimated there will be a market for about three million cars by 2000, with demand reaching five to six million by 2010. The plan also calls for conglomerates, with annual production capacities of more than 400,000 cars each, to be formed from the merger of two to three automobile manufacturing groups[2] (HKSTD March 15, 1996).

The electronics industry has become one of China's pillar industries. Between January and June 1995, the total output value of China's electronics industry amounted to 106.58 billion yuan, up 28.7% from the same period in 1994.

During the Ninth Five-Year Plan period, China is set to promote national economic information by implementing a series of Golden projects, with emphasis being placed on the Three-Golden projects.[3] Information resources will be put to effective use in achieving modern management in important areas such as banking, finance, taxation, industrial production, education, and macroeconomics control, as well as in achieving office automation for government departments. The application of electronic information technology will be promoted in the whole country to allow the people to become better informed.

The overall strength of the electronic industry will be further enhanced. The major economic targets for the year 2000 are:

1. Annual growth of over 20% for the whole electronic industry

2. Electronic industry total output value of 500-600 billion yuan (10% of China's total industrial output value)

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[2] There were 165 plants engaged in car assembly in China last year, each producing a little more than 8,000 automobiles on average. China has 22% of the world's population but produces only 2.5% of the world's automobiles.

[3] They are the Golden Bridge project which involves the establishment of a national public computer network system, the Golden Card project which is a network for promoting the use of credit cards, and the Golden Pass project which involves the establishment of a paper less transaction system for international trade.

3. Annual sales of 400-500 billion yuan

4. Exports of electronics products totaling US$25 billion (11% of China's total exports).

5. Emphasis on the production of integrated circuits, computers and computer software, and telecommunications equipment.

6. Consumer electronics development.

China will strengthen its ability to develop new products and utilize technological advancement to promote industrial development. Special attention will be paid to the four major areas of microelectronics technology, digital technology, software technology, and network technology. By the year 2000, new generations of products using digital technology will dominate the market. Also Chinese-language information processing technology and related products, digital program-controlled switched, color TVs, and VCRs will reach international advanced levels, and economy of scale will be achieved in production (HKTDC 1995).

China is aiming for exponential growth in its information technology industry by the year 2000, with massive increases in production of integrated circuit (IC) chips, computers and peripherals, telephones, and optic-fibers. According to the Ninth Five-Year Plan, by 2000, China will produce annually 2.5 billion computer IC wafers, a seven-fold jump over 310 million produced last year.[4] The total capacity of telephone exchange boards is also to soar to 174 million lines, more than double last year's figure of 85 million. China also aims to expand telephone sales by 2000; 7% of Chinese families are forecast to own a phone, up from 4.6% in 1995. Color television ownership is expected to jump to 60% from 42%.

The electronics industry is to become one of China's backbone industries. The country also plans to develop card-form equipment, new computer monitors and photo-electric equipment, and build up production and an export base for computers, peripherals, and boards. China aims to develop basic and application software according to international standards, laying the ground for their eventual export. The country also plans to improve the development and production of digital telephone exchange boards, mobile and optic-fiber communication equipment, and digital consumer electronics.

For long-distance telecommunications, the Five-Year Plan calls for building up an optic-fiber trunk line network.[5] By the year 2000, long-range, optic-fiber lines should have a total length of 210,000 kilometers. National information infrastructure facilities are to be built up, supported by broad-band multi-media digital technology. For conventional telephones, the country aims to build up and perfect a nationwide network with mainly program-controlled exchange boards. By the year 2000, the total exchange board capacity should reach 174 million lines, 89 million more than the 1995 figure.

Computer sales will take off exponentially when around 10% of families have a computer and social pressures encourage other households to buy. Rapid growth in household purchases of personal computers is expected in

[4] One of its tasks is the mass production of six-inch wafers with the 0.8 micron IC. The electronic industry is to mass produce eight-inch wafers with the 0.5 micron IC while at the same time carrying out research and development on 0.3 micron technology.

[5] Telecommunications is one of China's fastest growing industries. This year, Beijing plans to spend more than 100 billion yuan on telephone lines, switching equipment, and the like. That's 15 times more than it spent in 1990.

China after 220,000 families bought PCs for their homes in 1995. Sales of personal computers in China rose 54% last year from 1994.[6] (HKSTD March 18, 1996).

Shanghai is the site of one of the world's most advanced combinations of computers and telecommunications. By late next year, Shanghai subscribers should be able to order a movie, bank at home or hold a teleconference with people worldwide. International Business Machines Corp., the world's largest computer maker, is betting the system will work well enough to persuade telephone companies and governments in China to make it their model and IBM their supplier. Half of China's 31 regional telecommunication authorities are talking to IBM about building their own system,[7] IBM said (HKSTD, March 12, 1996).

[6] Household purchases of computers accounted for 20% of China's personal computer sales last year. Statistics show that about 5% of families of Shanghai, China's largest city, have bought computers, with the number expected to grow to 20% in 1997.

[7] There's the possibility of selling a big system to the Agricultural Bank of China to link computers in its 49,000 branches or to the Ministry of Railways, which must keep track of almost four million employees.

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